AURORA PULSED RADIATION SIMULATOR
United States Army Research Laboratory, Building 500
North of State Route 212, .5 miles west of Cherry Hill Road
Adelphi
Prince Georges County
Maryland

HAER No. MD-114

HAER
MD
17-ADEL,
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BLACK AND WHITE PHOTOGRAPHS

WRITTEN HISTORICAL AND DESCRIPTIVE DATA

HISTORIC AMERICAN ENGINEERING RECORD
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Location: United States Army Research Laboratory, Building 500, north of State Route 212, .5 miles west of Cherry Hill Road, Adelphi, Prince Georges County, Maryland

UTM Coordinates: 18.330730.4322210

Date of Construction: 1969-1971

Present Owners: United States Army [Infrastructure]
Defense Nuclear Agency [Simulator]

Present Use: Decommissioned; Simulator Disassembled

Significance: The Aurora Pulsed Radiation Simulator was the first gamma radiation simulator of its size and capacity built in the world. The simulator achieved a new plateau of nuclear effects simulation, able to test complete weapons electronics packages critical for both strategic and tactical nuclear weapons design. During the first half of its life, the Aurora Simulator primarily served military agencies and contractors in testing the warheads of intercontinental ballistic missiles [ICBMs]; during the second half of its life, the facility expanded its technical capabilities to test the hardening of very large finished systems, such as those for satellites.

Project Information: During 1995-1996, the Aurora Simulator is being disassembled inside its reinforced-concrete infrastructure. Removal of three-quarters of the capacitors in the Marx tank occurred in early 1995, with shipment to Arnold AFB, Tennessee, for reuse in the simulator Decade. Following final test shots for PORTS in September 1995 and decommission, disassembly will continue for the entire simulator, inclusive of drainage and removal of the insulating oil storage tanks. The Aurora Simulator will formally close in September 1996.

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I. HISTORICAL INFORMATION

The Aurora Pulsed Radiation Simulator (Building 500) is sited on the 137 acres of the United States Army Research Laboratory (formerly the Harry Diamond Laboratories [HDL]) in the immediate vicinity of Washington, D.C., at Adelphi, Prince Georges County, Maryland, and neighbors the Naval Surface Warfare Center (NSWC; formerly the Naval Ordnance Laboratory, NOL) at White Oak, Maryland. The facility is one of a historic and contemporary group of American nuclear radiation simulation facilities. Radiation effects simulators are defined by the capability of generating electrical pulses between 0.5 and 20 million volts (0.5-20 MV). The Defense Nuclear Agency (DNA; formerly the Defense Atomic Support Agency [DASA]) and the Department of Energy (DOE; formerly the Atomic Energy Commission [AEC]) sponsored these machines and their major modifications between the years of 1962 and 1989, at the height of the Cold War.

The Aurora Simulator resulted from a long period of experimental advancements in flash radiography begun in the laboratories of J.C. Martin at the Atomic Weapons Research Establishment (AWRE), Aldermaston, England, during the 1950s. These advancements continued in the U.S. during the early 1960s through the progressive design and engineering work of the Field Emission Corporation (FEMCOR), Ion Physics (IP), Physics International (PI), and Maxwell Laboratories, Inc., as well as through studies by major physicists at the DASA (DNA) and AEC (DOE) laboratories and at selected American universities. Originating in late World War II radiographic studies that used x-ray flashes to analyze explosions, flash radiography led to the realization that field emission flash x-rays could simulate radiation from a nuclear bomb. This important observation led to the development of small to moderate-sized testing machines, including FEMCOR's Febetrons (field emission betatrons) in ca. 1960-1962, used primarily for non-military purposes and operating at only 600,000 volts; IP's flash x-ray machines (FX series numbered by voltage); and PI's early Pulserad series. The Aurora Simulator, in the company of the 1965-1966, 1978-1979, and 1987-1988 Hermes I-III simulators operated by DOE at Sandia Base, New Mexico, is one of a select group of only four large American machines built to test complete nuclear weapons packages and, later, systems against the simulated effects of gamma radiation. Today only Hermes III remains operational.

A nuclear detonation produces a high-intensity prompt gamma pulse of transient duration that immediately affects all electronic devices in the area of the blast. A similar pulse of gamma ray radiation is achieved in the laboratory through massive acceleration of electrons, abruptly forced to give up their acquired energy in a series of collisions and thus transformed into very energetic photons. The produced radiation of the photon beam or field simulates that of gamma rays. Within the gamma radiation simulator group, Hermes I is transitional, codifying the 10-MV plateau experimentally reached through the FX 100 (a short-lived, failed machine) and the Pulserad 1590. The Aurora Simulator represented the capacity to produce a magnitude more electrical power than its immediate predecessors, or more than 10 million-million (10 trillion) watts. Its higher power allowed the creation of militarily useful high-intensity radiation. Its short electrical pulse simulated transient effects in complete electronic systems which previously could only be studied with nuclear detonations. However, Aurora could be fired many times a day, providing experimental control and repeatability, and Aurora did not produce any dangerous residual radiation. The Adelphi, Maryland, facility is a significant benchmark in the engineering and architectural design of a nuclear effects laboratory and, at its scale and intensity, was both unique and a first, worldwide, in the arena of Cold War nuclear physics.

The Decision to Build Aurora

In 1965-1966, DASA (the forerunner of DNA) initiated the serious U.S. development of nuclear effects laboratories. During the late 1950s and early 1960s, significant research in the British and American nuclear physics communities had demonstrated that progressively more sophisticated nuclear accelerators and reactors, as well as small-scale radiography/flash x-ray machines, made the diagnostic testing and refinement of nuclear weapons possible in other than the setting of an atmospheric (aboveground) or underground nuclear detonation. DASA went to the two American contractors understood to possess successful cutting-edge technology in the development of nuclear radiation simulators, PI, of San Leandro, California, and Maxwell Laboratories, of San Diego, California. Both of these private laboratories became captive research and development facilities for DASA/DNA, with large amounts of funding channeled into the work of nuclear effects simulation. While both companies had the capabilities to design the range of radiation simulators sought by the military, PI steadily focused on gamma x-ray and moderate bremsstrahlung simulators, and Maxwell concentrated on machines to simulate moderate bremsstrahlung, low voltage bremsstrahlung, and soft x-rays. Theoretically, PI and Maxwell were competitors, but in fact DNA's sponsorship of research and development alternated between the two companies. The idea for the Aurora Simulator was to build a full-threat level facility, enabling the gamma radiation testing and refinement of the completed top of a missile.

In the middle 1960s, AEC, DASA, and the U.S. military agencies, particularly the Air Force, understood that the advancements in flash x-ray machines, which had hitherto tested parts of missile packages, pointed to whole-systems testing and that atmospheric and underground nuclear detonations were prohibitively costly, relatively inefficient, and dangerous. The actual motivation, however, was not scientific achievement, cost-time analysis, or environmental concern, but rather a military strategic and tactical necessity. The Soviets had displayed the world's first antiballistic missiles (ABMs) in Red Square in May 1964, deploying the world's first ABM system surrounding Moscow in 1966. The achievement of ABMs altered the character of future nuclear war. Inbound U.S. ICBMs faced possible atmospheric direct nuclear detonation or the adjacent atmospheric nuclear explosion of a failed Soviet ABM, and thus it was anticipated that the electronics systems atop a missile would encounter the conditions of a nuclear explosion *before* achieving their strategic mission. Conversely, the U.S. needed to develop its own ABM system to protect itself against inbound Soviet ICBMs, with its ABMs requiring perfected hardening. DASA intended that the Aurora Simulator would first test the Spartan and Sprint ABMs, which the simulator did undertake in early 1972.

A Joint Chiefs of Staff decision in early 1966 activated the Phase I studies for Aurora. Involved in Phase I were Dr. N.F. Wikner, DASA Deputy Director for Science and Technology; Peter H. Haas, formerly of the U.S. Army's HDL and special assistant to Dr. Wikner at DASA; Major Carlton Jones, DASA project officer for the Aurora Simulator; and Frank J. Thomas, Assistant Director of Defense Research and Engineering, Nuclear Programs. DASA called together a group of professionals to analyze available and anticipated technologies and evaluate what was needed and what was possible ("Aurora Facility" 1972, 25). Simultaneously, DASA initiated the process of site selection for Aurora. DASA wanted the gamma radiation simulator collocated at an existing military laboratory facility and effectively had to choose between the Army and Navy laboratories in the Washington, D.C., area and the Air Force Weapons Laboratory (AFWL) in New Mexico, adjacent to the AEC Sandia Base, at Kirtland Air Force Base (AFB), Albuquerque. (The AFWL is now known as the Phillips Laboratory.) Intense competition between DASA and the Air Force, as well as the Air Force's immediate proximity to Sandia and relative historic lack of cooperation with DASA, made the choice either Navy or Army (Caldwell 1996).

Several individuals closely involved in the Phase I studies had previously worked for HDL; worked for HDL at the time of the DASA consideration; or had previously worked elsewhere with each other. In particular, Pete Haas may have been the influential figure in the decision making. Physicist Paul A. Caldwell, a participant in the Manhattan Project while a student at the University of Minnesota and with the Naval Research Laboratory (NRL) from 1942-1959, had been with HDL since 1959 and was the second critical figure in what was ultimately an HDL choice. The Navy handled the architectural and engineering contract for the facility through the NOL, donating land for a new HDL site adjacent to its own facility at White Oak, Maryland. HDL moved from its downtown Washington, D.C., site to what is today Adelphi, upon completion of the Aurora Simulator. During 1966-1967, the small nuclear effects physicist community generally knew of the upcoming Aurora project, with those individuals trained under J.C. Martin at Aldermaston, in particular, knowledgeable. It was assumed that either PI or Maxwell would build the simulator. Physicist Alexander G. Stewart, formerly of IP near Boston, left that company for California, joining the aerospace firm of Philco-Ford to be near PI and news of the Aurora project. During 1967, he directly approached HDL, putting himself forward as the potential lead physicist for operation of the not-yet-designed simulator. Stewart, originally from Scotland, achieved his U.S. citizenship in San Francisco that year. DASA awarded the Aurora contract to PI in June 1968. Before the close of 1968, DASA placed Paul Caldwell in charge of Aurora at HDL, and Caldwell in turn hired Alexander Stewart. Caldwell and Stewart then brought on physicists Robert C. Lamb, who had worked with Caldwell at the Nevada Test Site and had been at HDL since 1966, and Dennis Whittaker. Therefore, the research and development phase for the Aurora Simulator at HDL included four people. The project officer for Aurora was Major Clayton S. Gates (Caldwell 1996; Kerris 1995; Poirier 1996; Stewart 1995).

Phase II began with staged design development and review, from mid-1968 through mid-1969, with its results formalized as the Aurora Diode Experiment (ADE). AWRE's J.C. (Charley) Martin, who had trained both Alexander Stewart and the designer of the Aurora Simulator at PI, Ian Smith, served as a godfather to the design reviews, attending them as an advisor to DNA. The ADE required that PI build and test one-quarter of the Aurora Simulator near its California office. Constructed at Tracy, California, the one-quarter simulator (with one Marx generator, one Blumlein network, and one bremsstrahlung transmission tube) achieved experimental success in May 1970 ("Aurora Facility" 1972, 25). Overlapping Phase II, Phase III undertook the construction of the infrastructure for the simulator at Adelphi. The NOL awarded the architectural and engineering contract to Gilboy, Stauffer, Giombetti, Skibinski, and Davies (GSGS&D) of Clark's Summit (near Scranton), Pennsylvania, in 1969. GSGS&D, with Randolf J. Stauffer as project manager, submitted its final drawings to the Navy in October, following multiple meetings held in California with HDL, DASA, and PI. Construction was initiated in December 1969 (Stauffer 1996). Assembly of the simulator itself at Adelphi began in July 1970; the Navy accepted the completed building in January 1971 ("Aurora Facility" 1972, 26).

Beginning in 1971 and early 1972, the HDL Aurora group expanded from its research and development core, with the first test conducted for McDonnell Douglas on the Spartan flight control set in April 1972. PI provided early support, but was subsequently phased out of direct involvement. The total group at the Aurora Simulator stabilized at about 20. Technician Al Poirier joined Aurora from Maxwell Laboratories, following a two-and-one-half year assignment monitoring the service contract for an IP machine at the AFWL in Albuquerque, in June 1971; Poirier had worked with Alexander Stewart at IP in the middle 1960s. Physicist Klaus G. Kerris arrived from the nucleonics division of Hughes Aircraft in Los Angeles in August; Kerris had worked with Caldwell at the Nevada Test Site while with Hughes. In ca. 1973 physicist Stuart Graybill from IP, who had worked with both Stewart and Poirier, joined the Aurora group. Physicist George A. Huttlin, as an immediate Ph.D. graduate from Notre Dame, came to Aurora in 1975 (Huttlin 1995, 1996; Kerris 1996, Poirier 1996).

Managing the Facility

Military agency and contractor test shots at the Aurora Simulator partially replaced diagnostic testing at the underground Nevada site near Las Vegas. Aurora tests, in conjunction with those at smaller laboratories, also complemented continued tests at the Nevada site until the ceasation of underground nuclear denotations. As envisioned and marketed, the Aurora Simulator could accommodate as many as six to 13 test shots in a single day, while testing at the Nevada Test Site occurred at intervals no more frequent than once in three months. Costs for a day of Aurora tests, a unit of measurement referenced as the "Aurora-user reimbursed customer day" (Agee 1996), began in the range of $2,000-3,000 in 1972; were at about $5,000 per day in mid-1984; and concluded in 1995 at $11,500 per day. In 1984 the customer charge represented approximately one-third of the actual costs of operating the Aurora Simulator for a day ("The Aurora Gamma Ray Simulator" 1995). The DNA subsidized the remaining two-thirds of the test costs, or $10,000 per customer day in 1984. The DNA constructed the Aurora Simulator for about $16 million, inclusive of $2.6 million for the reinforced-concrete structure that housed the simulator. A single underground nuclear weapons test at the Nevada Test Site ran to similar dollars. In underground tests, any experiments could be set up only once in the tunnels, with the achieved data ranging from useful to useless. All associated materials were hence radioactive and could not be reused. At Aurora the bremsstrahlung (which simulated the gamma radiation) was produced electrically without any nuclear disintegration; thus, neither the objects tested nor the test chamber itself were left irradiated. The Army, using Productivity Capital Investment Program (PCIP) funds, sponsored about $6 million in upgrades at Aurora in the middle and late 1980s.

By mid-1982, users had undertaken more than 3,750 test shots; by late 1990, the figure had approximately doubled, climbing to 7,400 shots ("Aurora, at 10, Still Mightiest Flash X-Ray" 1982; "Aurora Trivia" 1990). At the conclusion of the simulator's active testing, in late 1995, a total of 9,100+ test shots had occurred at the facility (Huttlin 1995). In Aurora's first decade, the average number of customer-user days was 40 per year. During this period, the test cell was in active use about 15 percent of the absolute available time. Assuming an underground test, as a single coordinated event, to be the equivalent of an Aurora test day, and disregarding the inherent environmental hazards and non-renewable nature of the specific real-life test facilities, an underground test site was in active use only about 1.5 percent of the absolute available time. Peak single-day usage at Aurora before 1982 was 66 test days per year. During the final period at Aurora, 1982-1995, reflective of significant facility upgradings, new strategic and tactical policies, and dynamic business management, the number of customer-user days per year more than doubled, with the peak year occurring in 1987 during the Reagan presidency at 170 user days (Agee 1996). Over its life span, Aurora was remarkably efficient.

In April 1972, McDonnell Douglas conducted the first test at the Aurora Simulator on the Spartan ABM flight control set. Considered a critical first exercise, the test involved multiple test shots over a period of months. McDonnell Douglas bought the Aurora staff chicken dinners to celebrate the success of the experiment. Typically, an agency or military contractor attended two or three pre-meetings at Aurora to become familiar with the facility and to set up its equipment; testing subsystems first, over a several-week period; returning to its own facilities for internal refinements of the weaponry for as long as a few months; and finally, concluding its work on that stage of the weaponry through a return to Aurora to test the whole package. Daily operations during tests involved careful mustering of all personnel before actual firing into the test cell. During testing, the Aurora Simulator, as originally constructed, required maintenance every several days, with a two-hour draining of the insulating oil from the Marx tank and going inside of the machine. The first year at Aurora was understood to be a shakedown cruise, a time to learn the characteristics of the machinery and to revise, fix, and change needed features of the test facility inclusive of operations procedures. After the completion of the year, J.C. Martin congratulated the Aurora physicists and technicians for getting the landmark equipment to actually work (Stewart 1995). Between April 1972 and September 1995, DNA supported 287 recorded tests at the Aurora Simulator; the average number of test shots per test, 1972-1995, was just under 32 (Aurora Test List 1992; Poirier 1996). The actual number of test shots for a particular test varied widely, with some contractors requiring only a modest number of shots and others needing a composite total of a month of full test days. Typically, contractors who were testing specific weaponry in development were motivated through the specifications with their customer to keep the number of test shots to a minimum; such packages had a limit to the amount of radiation that they could receive without damaging the final product to be turned over to the customer. In contrast, Aurora Simulator staff, testing experimentally to validate a methodology rather than refining the design of equipment, usually sustained a very large number of test shots per test (Huttlin 1996).

Architectural and Engineering Design

GSGS&D designed the reinforced-concrete infrastructure that housed the Aurora Simulator in 1969, with Randolf Stauffer as Project Manager. The Aurora facility was the first of approximately 12 specialized contracts undertaken by GSGS&D for the Chesapeake Naval Facilities Engineering Command (NAVFAC), Washington, D.C. Founded in ca. 1960 as an engineering firm, the Gilboy Company expanded to include architectural services in 1964. Its primary partners at the time of the Aurora construction were John P. Gilboy, Jr. ("G"), Stauffer ("S"), Robert J. Giombetti ("G") James T. Skibinski ("S"), and Edward T. Davies ("D"). Stauffer was the firm's resident architect, while Gilboy, Giombetti, Skibinski, and Davies were all project engineers. After ca. 1983/1984, Davies left the firm; in 1993, the subsequent firm, GSGS&B, was sold to Hillier of Princeton, New Jersey. GSGS&D had established itself near Scranton, Pennsylvania, due to the established residences of its partners. During the Aurora commission, the firm supported about 55 personnel; a draftsman worked with Stauffer on the Aurora Simulator infrastructural design. GSGS&D had responded to the Aurora request for proposal through the *Commerce Business Daily*, with no pre-existing military design experience. The firm, however, had competed for Navy contracts unsuccessfully for the prior half dozen years and had acquired an understanding of Navy needs. GSGS&D met with DNA and PI extensively during the design process, with the needs of the physicists preeminent. Security issues were a major concern at the start of the joint meetings, but the tensions of including members of a civilian architectural/ engineering firm lessened as it became clear that the fragments of overheard technical discussions were incomprehensible to GSGS&D. The primary architectural problem of the Aurora design, as interpreted by GSGS&D, was to integrate the high-bay simulator space with the single-story office and laboratories wing. Situating the monolithic reinforced-concrete structure into the hill, and continuously banding the differing heights with textured concrete paneling, solved these aesthetic issues. Infrastructural engineering challenges of the facility focused on the foundation support system for the structure, especially that of the rail tracking in the machine bay, the insulating oil pumping system and the design of the storage tanks, and the electro-magnetic shielding of the data room.

GSGS&D's design for the infrastructure housing the Aurora Simulator won one of four American Institute of Architects (AIA) First Honor Awards in the NAVFAC Biennial Awards Program for Distinguished Architectural Achievement in 1972. Other honorees of that year were Stevens & Wilkinson's Bachelor Officers Quarters and Mess, Navy Supply Corps School, Athens, Georgia; Loebl Schlossman Bennett & Dart's Service School Barracks, Naval Training Center, Great Lakes, Illinois; and Delawie, Macy & Henderson's Thompson Medical

Library Addition, Naval Hospital, San Diego, California. Two additional awards of merit in the competition were Mackinlay/ Winnacker/McNeil & Associates' Price Elementary School, Mangilao, Guam, Mariana Islands; and Hayes, Seay, Mattern & Mattern's Chemistry Laboratory, NRL, Washington, D.C. AIA jurors for the AIA/NAVFAC competition were William A. Carlisle, chairman; John Carl Warnecke, FAIA; and architectural student Cortlandt G. Liddell, University of Illinois, Chicago Circle. GSGS&D's architect for the Aurora facility, Randolf Stauffer, served as the chairman of the subsequent AIA/NAVFAC competition in 1974. Of curious note, the featured photograph of the Aurora Simulator infrastructure published in the AIA *Journal* as a result of the 1972 competition showcased the facility looking south to north, across the holding pit for the oil tanks toward the windowless high-bay, before the tanks were installed and before the full berming and landscaping immediate to the pit. From this vantage point, the monolithic, artistic character of the structure is emphasized, while neither the industrial realities of the huge steel storage tanks, nor the utilitarian practicality of the high-bay vents, the office windows, and the loading docks are visible. In a security sense, the chosen view tells an observer almost nothing; it is also a view that could never be seen again, once the tanks were emplaced and the berm work completed ("1972 Naval Facilities Awards Program" 1973, 44-46).

GSGS&D finished the Aurora facility for $2.6 million, exclusive of the simulator costs. Blake Construction Company, of Washington, D.C., handled the physical construction, supervised by the Chesapeake Division of NAVFAC. Before the Aurora Simulator infrastructure was completed, GSGS&D took on a second Navy specialized assignment, the $1,215,000 Vulnerability and Hardening Laboratory at the neighboring NOL (subsequently NSWC). The second GSGS&D nuclear radiation effects laboratory tested Navy electronic systems, also containing a hot cell like that at Aurora. Finished in 1973, the NOL facility led to a three-phase Electromagnetic Test and Development Laboratory built between 1976 and 1982 at a total cost of $12.7 million at the other major Washington, D.C., Navy test laboratory location, the NRL. By the middle 1980s, GSGS&B (the successor firm to GSGS&D) had expanded to 300 personnel, designing a wide range of buildings for clients internationally.

Later commissions included a large group of department stores for Lord & Taylor and varied work for ITT, IBM, and Sheraton Hotels. By this date, GSGS&B had an office in New York City (Stauffer 1996).

Nuclear Effects Testing and Weapons Development: The First U.S.-U.K. Ties

Before the construction of Aurora, no situational environment existed that was of sufficient power and size to evaluate and refine major Cold War weapons systems exclusive of the atmospheric or underground test site of an actual nuclear detonation. The study of nuclear effects, related to the escalating megatonnage of atomic and then hydrogen bombs, was a part of the development of nuclear weaponry from its earliest days and, in the physics community, was always an international research effort. Discovery of the neutron by British scientist Sir James Chadwick in 1932 initiated dynamic laboratory study among a small group of preeminent scientists in Germany, Denmark, the former Soviet Union, Austria, France, England, and the U.S. In late 1938, German scientists Otto Hahn and Fritz Strassmann proved that heavy atoms, experimentally uranium, could be split by neutron bombardment and that the resultant fission released enormous energy. World War II disrupted the international exchange of 1930s pure research, crystalizing scientists' efforts into German, Soviet, British (aided by emigrant German and French physicists), and American camps (Simpson 1983, 20). The earliest Allied forces work toward an atomic bomb occurred in England, initially named the Atomic Energy Project and, by 1941, code-named Tube Alloys (Gowing 1974). In the U.S., scientific nuclear experimentation came under the jurisdiction of the Army in mid-1942 as the Manhattan Project, with a military effort focused to develop an atomic bomb. The recognized lead of the British scientists not withstanding, economic resources for escalated research and development rested heavily with the Americans, and between June 1942 and early 1944 scientific-military discussions extending to nuclear weapons development abruptly ceased at the insistence of the U.S. By mid-1944, cooperation had been reinstated, with 50-60 British scientists in the U.S. participating in nuclear weapons and energy work by the war's close (Simpson 1983, 21-27). Most critical for Cold War nuclear effects research, the British team had among its membership 34-year-old Dr. William G. Penney.

Dr. Penney had begun his career as an assistant professor of applied mathematics, theoretical physics, and theoretical chemistry at Imperial College, London, in about 1937. During the first years of World War II he worked for the Home Office and the Admiralty on the effects of high explosives. From mid-1944 through 1945, Penney worked at Los Alamos as one of 19 British scientists included in the U.S.-U.K. nuclear weapon development team, with a specialized interest in theoretical bomb effects. Described as a brilliant and elegant mathematician, who got on well with the Americans, Penney was one of a kind and in the words of J.C. Martin, "a most remarkable man" (Caldwell 1996: quotation from correspondence, Martin to Caldwell 1996). The Americans considered him to be among the five most distinguished British contributors to the work at Los Alamos. During the July 16, 1945, Trinity test detonation, Penney's task was "to observe the effect of radiant heating in igniting structural materials" (Hewlett and Anderson 1962, 310, 377). Recently deceased, Dr. Penney, to become Lord and then Baron, may well have been the leading international expert on nuclear effects.

To the Americans, Penney was indispensable and repeatedly recruited without success as a permanent member of the U.S. nuclear team; these facts are illustrated through two of the numerous events that occurred in the first years of nuclear weapons effects work. Dr. Penney was one of two British observers present in the observation aircraft during the dropping of the second American atomic bomb over Nagasaki on August 9, 1945, and, visited both Hiroshima and Nagasaki after the blasts to measure bomb effects. The Nagasaki episode was unquestionably remarkable. Sir Chadwick, head of the British scientists group at Los Alamos, had conceded that the Japanese bombing was to be exclusively an American military effort. Even so, he had managed to have two British observers, Group Captain V.C. Cheshire and Dr. Penney, accompany the Americans to Tinian Island, from which the Hiroshima and Nagasaki sorties were flown. (Cheshire's experience was entirely military, associated with British bombing raids on Germany.) Restricted by the local

U.S. commander from flying in the observation plane during the Hiroshima drop, Penney and Cheshire were granted literally last minute permission after an appeal by Chadwick to Washington, D.C., to fly with the second drop. The first observation team, American, got no photographs during the bomber-observation flight over Hiroshima. The second observation team placed all of their expectations in Penney to photograph the fireball and blast wave, to estimate bomb yield, and to analyze effects. Due to the belated permissions, the August 6th observation plane missed its rendezvous with the bomber at Nagasaki, an element of organizational mishap that ultimately precluded Penney's photography. Dr. Penney did, however, see the Nagasaki drop and detonation from the air at a distance, one of only a handful of men in the world to witness first-hand either of the Japanese detonations from that perspective (Hewlett and Anderson 1962, 379-80). Penney was also present as a member of the American Los Alamos team, at the request of the Navy, during the setup and detonation of the two U.S. atomic bombs over the Bikini Atoll in the Marshall Islands on July 1 and 24, 1946. At the Bikini tests, Penney was among 10 British representatives present; five were kept secret, and only two were officially sent as observers for the British government in their role as a member of the United Nations Atomic Energy Commission. Penney spent most of the summer of 1946 working with the Americans in the Pacific, in charge of the blast effects studies, writing subsequent reports on the observed and evaluated effects of the two detonations, and invited to secret meetings in the U.S. afterwards to discuss the results (Gowing 1964, 266; Gowing 1974a, 1:112-13; Gowing 1974b, 2:4-7, 442).

In August 1946, Dr. Penney returned to England to continue in his post as Chief Superintendent of Armament Research in the Ministry of Supply. He had known as early as May, before the Bikini tests, that he would be asked to head the program to develop Britain's bomb. In August, Penney was one of three individuals hired to run the British atomic energy program, with the expected tasks before him. That same month the U.S. passed the Atomic Energy Act (AEA), making all exchanges on nuclear weapons designs and fissile materials between the U.S. and Britain illegal without Congressional agreement. The AEA made the exit of the remaining British nuclear scientists assured and reinstituted independent work on the part of the two nations paralleling the break during 1942-1944. The only exception to a U.S.-U.K. exchange of information was in regard to information on nuclear weapons effects (Simpson 1983, 76). Within his traditional-appearing post with the Ministry of Supply, Penney initiated his plans for an Atomics Weapons Section, submitting these as secret written documents to the Marshal of the Royal Air Force, Lord Portal, in November. At this time, Dr. Penney listed 18 individuals whom he wanted recruited in the near future. Britain made the ministrial decision to proceed with the atomic bomb in January 1947, although Penney did not formally initiate his atomic weaponry program until May. Finally, during the winter of 1946-1947, Dr. Penney served as a scientific adviser to the British representative at the American AEC. Penney's first work on establishing nuclear weapons development for the U.K. was disguised under the official label of high explosive research (Gowing 1974a, 1:180-81; Gowing 1974b, 2:442).

In June 1947, Dr. Penney invited a select group of 34 scientists and engineers to begin work on the British atomic bomb, envisioned to be similar to that dropped by the Americans on Nagasaki. Most came from within establishments of the Armament Research Department, particularly from Fort Halstead and Woolwich. Significantly for American study of nuclear effects, and ultimately for the design and engineering of the Aurora Simulator, Penney, from the first, understood the extensive analysis of the effects of the bomb as of primary concern. Continuing the secrecy of 1946, Penney's group received the name of High Explosive Research establishment (HER or, alternately, HERE) (Gowing 1974b, 2:442-45). Dr. Penney formally set up HER in August 1947. Anecdotally, Penney told invitee J.C. Martin that the establishment had only really gotten underway with Martin's arrival in mid-September (Caldwell 1996: correspondence, Martin to Caldwell 1996). Dr. Penney's first task was to develop the British atomic bomb; simultaneously, HER was responsible for basic nuclear research as well as development, weapon manufacture, and test. Between the autumns of 1947 and 1949, however, Penney encouraged a small subsection of his group to focus heavily on nuclear effects. In the group were Martin, "a most original scientist," J.J. McEnhill and W.J. Moyce; this unit produced a 17-part series of reports on their results in nuclear effects laboratory experimentation. Penney himself authored several of the reports. Climaxing these critical efforts, HER held a highly secret conference at the Royal Institution in the late summer to brief military and civil defense officers on the conclusions of the effects group (Gowing 1974b, 2:455).

The first work of HER was physically set at the Ministry of Supply's Armament Research Department at Fort Halstead in Kent. By 1948, it had become obvious that the mission and needed security of the HER scientists required a segregated, fully equipped, permanent site; however, initially Dr. Penney was opposed to the separation from the Armament Research Department. During 1949, talks between the British and the Americans concerning a free-flow of nuclear weapons research information between the two countries and establishing a joint group of scientists again at Los Alamo consumed much of the year. Soviet detonation of its atomic bomb on August 29th heightened the pros and cons of the discussions. Penney himself had headed a British delegation of scientists to a high-level military meeting in Washington, D.C., in mid-September to discuss gathered and analyzed information on the Soviet detonation (Hewlett and Duncan 1972 [reprint of 1969], 365). Penney was intended to be among the first scientists to reintegrate with the American team should the broader negotiations conclude successfully. However, the U.S. worried about the potential vulnerability of the U.K. and felt vindicated in their concerns with the early 1950 arrest of the British scientist Klaus Fuchs. Fuchs had worked at Los Alamos, returned to England, and passed significant information to the Soviets. From this point forward, the building of a British Los Alamos was assured, with an airfield at Aldermaston in Berkshire chosen for the site in April 1950. The first hot laboratory was ready for operation by the end of the year. By 1971, after 20 years of expansion, Aldermaston included more than 1,000 buildings, exclusive of more than 2,000 housing units on site (Gowing 1974a, 1:273-98; Gowing 1974b, 2:17, 194-200, 446, 449, 450). At Aldermaston, J.C. Martin initiated the work in flash radiography that would lead to the latter-day American effects laboratories. As a colleague of Dr. Penney's at Aldermaston, Martin trained the physicists who would immigrate to the U.S. during the 1960s, there designing the preeminent radiation effects simulators inclusive of Aurora.

The Mature British-American Nuclear Physics/Pulsed Power Community

J.C. Martin, recently retired, was a diagnostician. At Aldermaston he directed experiments and studies focused on how nuclear bombs worked. Essentially, he wanted to stop stages of the explosive event caused by nuclear detonation, for close analysis, as it imploded upon itself. His first objective was to find an equivalent to taking a picture of the core, what physicists reference as the pit, within the generated cloud of gas and debris. Martin and Penney wanted to clarify what could not be seen literally. Radiographic research was the only way to scientifically look at the event of the nuclear bomb. Radiography, typically through the action of x-rays, produces images on photographic plates. Martin developed flash radiography, with more intense bursts of x-rays as the mechanism creating the photo-plate imagery, to look at explosive experiments in the laboratory and at atmospheric nuclear tests, with the larger explosions requiring more energetic techniques. Aldermaston, specifically through Martin's group, was the international leader in the development of pulsed power for the flash radiography associated with nuclear detonations and, subsequently, for the effects simulation needed to refine hardened weapons design (Stewart 1995; Caldwell 1996).

In addition to Penney and Martin's predilections as scientists, two points of view, one philosophical and the other practical, directed the British path toward nuclear effects simulation. In the very early 1950s, those guiding the government of the U.K. regarded the atomic bomb as primarily a political, rather than a military, weapon; the art was more important than the article. Britain did not have the financial resources of the U.S., although expenditures toward the bomb were generous and significant. Britain hoped to combine its efforts with those of the U.S. to save on repetitive research and development, as well as costs, on the one hand, and Britain assumed that in the event of nuclear war, the U.S. would not abandon the U.K. as it might Europe. Thus, large stockpiles of weaponry were not envisioned as critical, while having first-rate nuclear technology and understanding, with some immediate stockpiling, was interpreted as an absolute necessity (Simpson 1983, 76). The U.S., conversely, increasingly moved away from the decision to share research and development, with the exception of non-weapons-design effects. The U.S. argued for no production or stockpiling of critical nuclear weaponry components in the U.K., anticipating that British bombs would be stored in Canada and that there would be common Anglo-American testing ranges. The U.S. became progressively less flexible as the 1950s unfolded, paralleling its lessening dependence on British Belgian Congo uranium ore (Simpson 1983, 77-86).

Thus, practically, Dr. Penney needed to find a way to test the British atomic bomb, scheduled for a first trial detonation in 1952. Penney made several trips to the U.S. during 1950-1951, requesting use of the American Pacific Test Site, Eniwetok. By late 1950, with no agreement forthcoming, Penney opened research and negotiations for other locations. Simultaneously, he considered seven sites in Canada and additional sites in Australia, desiring specifically to test the British atomic bomb in a shallow port simulating the London harbor. In late 1951, the U.S. finally rejected the British request for the use of their Pacific site, but made alternative proposals for joint testing in Nevada. The Nevada Test Site had been in operation since January 1951 for explosive tests of low-yield nuclear weapons, not high-yield bombs such as were tried at Eniwetok, and, of course, offered no possibility of a shallow-port trial (Simpson 1983, 59). By this date, Penney had decided to go ahead at the Monte Bello Islands off the northeast coast of Australia for the initial U.K. event. The October 1952 test was the 33rd atomic detonation since the close of World War II; 29 had been American trials, and three were Soviet (Gowing 1974b, 2:476-80). Atmospheric testing continued in 1953 in Southern Australia near Woomera. While these large-scale tests went forward, Aldermaston also developed lower-yield nuclear weaponry and in its endeavor was greatly influenced by the lack of a nearby test range. Los Alamos had the Nevada Test Site; Aldermaston chose to limit the number of atmospheric weapons development tests it undertook, instead placing efforts in the laboratory and using the costly, and difficult to orchestrate, atmospheric tests as fine tuning after an accumulation of labwork (Simpson 1983, 94). Although Dr. Penney did consider the location of an atmospheric test range in Britain itself in 1955, and subsequently in Scotland, Aldermaston's laboratory emphasis, from a very early date, was a key distinction between the British and American approach to nuclear weapons design (Blakeway and Lloyd-Roberts 1985, 10). With no British atmospheric testing during 1954-1955, the passage of the British Atomic Energy Act and establishment of the U.K. Atomic Energy Authority (UKAEA) equivalent to the American AEC in mid-1954, and the accelerated pressures in weaponry development due to the detonation of the much more powerful hydrogen fusion devices by both the U.S. and the former Soviet Union during late 1952-1953, J.C. Martin's team of scientists began to direct the technology of flash x-ray machines toward effects simulation useful in active nuclear weapons development (Simpson 1983, 95, 97).

During the middle and late 1950s, J.C. Martin drew a talented group of young physicists from British universities to Aldermaston, beginning work toward the serious development of nuclear radiation effects simulators (Stewart 1995). The HER became the AWRE (Blakeway and Lloyd-Roberts 1985, 146), achieving pronounced comparison with the American Los Alamos, and in late 1954 the U.K. made development of a megaton hydrogen bomb a priority. From 1952-1958, the U.S. remained ignorant of the significant accelerated progress made at Aldermaston. The AEA of 1946, revised in 1954, had effectively made exchange of research and development information on nuclear weapons design impossible, and Martin's 1950s work toward radiation effects simulation augmented such design. The situation changed dramatically in 1958. In October, after only seven British atmospheric tests, the U.S. and the former Soviet Union agreed to a moratorium on all nuclear atmospheric testing; the U.K., through political pressure, joined the moratorium, which lasted until August 1961. Simultaneously, after long evaluation in 1957, the Congress amended the AEA of 1954, stipulating possible exchange of detailed information with nuclear allies on nuclear weapons design, development, and production. The Anglo-American Military Agreement for Cooperation of 1958 further allowed the U.S.-U.K. exchange of classified information on nuclear weapons. After August 1958, British and American nuclear scientists visited each other's research, development, and production plants. Aldermaston contributed its peak production of fissile cores to the British nuclear weapons program during 1959-1964; during the early 1960s, J.C. Martin's group pushed the radiography of fast processes to major breakthroughs of achievement, reaching electron beam parameters in the megavolt and 100-kiloampere range (Simpson 1983, 97, 106, 129-30, 137, 139, 142, 157; Fleischmann 1975, 35).

After the dynamic expansion of the 1950s, Aldermaston began facing an opposite dilemma in ca. 1960. Britain planned a steady-state nuclear weapons inventory for the 1970s, and in 1961 a 12-year program to reduce, or rundown, Aldermaston activities became formal. Aldermaston staffing was to achieve a 36 percent contraction by 1973. Also in 1961, the former Soviet Union and the U.S. resumed atmospheric tests; the U.S. conducted its last atmospheric test at Nevada in July 1962, thereafter testing underground at the continental site. The U.S. and the U.K. had a close nuclear relationship at the resumption of testing. As a result, the U.S. granted the U.K. use of the Nevada site for underground tests, and the U.S. received atmospheric use of the British test site on Christmas Island in the Pacific. In July 1963, the U.S., U.K., and the former Soviet Union agreed to a Partial Test Ban Treaty, prohibiting atmospheric nuclear testing, but placing no limitations on underground trials; the treaty motivation stemmed from the foreshadowed threat of ABM development (Simpson 1983, 157, 160, 162, 163). These combined events, staff contraction at Aldermaston, U.K. activity at the Nevada Test Site, and the Soviet ABM threat, encouraged an exodus of British physicists to the U.S. to continue their innovative work on nuclear effects simulators. And although J.C. Martin himself stayed at Aldermaston, he made many trips to the U.S. during the 1960s and 1970s to work with his dispersed former team members and their new American colleagues.

At least five of Martin's physicists immigrated to the U.S., with three arriving in ca. 1962 and two later in the decade. First arrivals were Alexander Stewart, Roger White, and Stuart Denholm. Stewart and Denholm hired with IP in Boston; White hired with Maxwell in San Diego. Stewart had worked on the unconventional generation of pulsed power, that is flash x-rays, at Aldermaston in 1959-1962 and had been present for a test at the Nevada site in 1959, working with Pete Haas who would later be the key to Stewart's hiring for Aurora (Stewart 1995). In 1967, Ian Smith immigrated to the U.S., hiring at PI in San Leandro and winning the contract for the design of the Aurora Simulator the next year. Smith's work at Aldermaston, like Stewart's, began in 1959, immediately following graduation from St. John's College, Cambridge. Smith pioneered work in pulsed power and is considered a leader in the elite community in the company of Martin himself (Stewart 1995). In 1980 Smith left PI to found Pulse Sciences, Inc. (PSI), a company active in contemporary leading nuclear radiation simulator design (Martin and Rose 1983, v). In 1983, the pulsed power community awarded the Erwin Marx award to Smith, in part for his work on Aurora ("the Aurora Gamma Ray Simulator" 1995). The fifth physicist, Philip D'Arcy Champney, had worked with Martin's group at Aldermaston from 1957 to 1968. He then visited the Cornell University Laboratory of Plasma Studies, beginning work in pulsed power, to set up a high current electron beam accelerator. In 1969 he immigrated to the U.S. permanently, joining Ian Smith at PI and in 1980 at PSI. Champney's first experiments at the AWRE had focused on diagnostics for a British atmospheric test at Maralinga, Australia, using high-speed cameras and radiography. Champney died of cancer in 1991, most recently recognized for his production of subnanosecond rise time pulses (White and Prestwich 1991).

Evolution of Nuclear Radiation Effects Simulators

After the signing of the Partial Test Ban Treaty in 1963, AEC (DOE), DASA (DNA), their military contractors, and American universities began to explore roles for flash x-ray machines in the testing and design refinement of nuclear weapons. During 1960-1962, the nuclear effects business saw its first sustained stimulus in the U.S. The American military initiated its refocus towards simulators, with a special interest in machine-produced simulation of gamma rays. FEMCOR, a start-up company in McMinnville, Oregon, formed by individuals who had previously worked at the AEC Sandia laboratories, is credited with the first American efforts in ca. 1960-1962. Its flash x-ray machine, the Febetron, was very, very small, but sometimes could be used with tests on explosions (Stewart 1995). The Febetron works on what Dr. Forrest (Jack) Agee terms the "piece-part level" (Agee 1996). Subsequently purchased by Hewlett-Packard, FEMCOR still makes desk-top flash x-ray machines, useful for testing electronics (Kerris 1995).

At about this same time, IP developed the first machine in its FX series, the FX 25. The USAF Weapons Laboratory at Kirtland AFB, the AFWL, bought the machine, the very first IP FX installed. (The machine subsequently went to the White Sands Missile Range [WSMR], an Army installation near Alamogordo, New Mexico [Poirier 1995].) Soon thereafter, HDL wanted a flash x-ray machine that could parallel the radiation effects simulation work being done by Aldermaston's Martin. Only FEMCOR responded to the DASA request for proposal, and HDL remained unsatisfied, feeling that FEMCOR was proposing to take its technology further than it could go. HDL then went directly to Dr. Martin for advice. Almost immediately, Alexander Stewart left Aldermaston for IP and became project manager for the FX 45, specially named the HIFX 45 for its installation at HDL in 1964 (at its earlier site on Connecticut Avenue in Washington, D.C.). Stewart received the Industrial Research 100 Award for HIFX. Approximately six customers purchased the FX 45, including General Electric, Raytheon, and military buyers in Sweden and France. The machine was four times the size of the FX 25, operating at nearly double the voltage, and was a machine that could be pushed to 7.1 MV. Next, IP built the FX 75 for Boeing in Seattle, installing the simulator in 1967. The final FX machine, the FX 100, achieved the simulator's maximum potential, operating only for three months at the AFWL in early 1969. A 10-million volt machine, the FX 100 tested the limits of the Van de Graaff generators that powered it. With the Van de Graaff generator, production of higher voltage required ever-greater length, with the generator columns cantilevered one to the other until it mechanically could not sustain itself across the adhesive support joints. IP, a friendly spinoff company from High Voltage Engineering (HVE) who had developed the Van de Graaff generator decades earlier, ceased to be at the cutting edge of nuclear effects simulator design with the FX 100. The J.C. Martin physicists, and others who focused on the development of the pulsed power industry, began to go elsewhere ca. 1966-1968. Alexander Stewart went to a private military contractor in the San Francisco Bay Area to be physically near events unfolding at PI (Poirier 1995; Stewart 1995).

At the same time as the development in the FX series, two other American companies, Maxwell Laboratories and PI, both in California, began to design radiation effects simulators using the Marx generator as their power source. The Marx generator is comprised of many large capacitors, charged in series and discharged in parallel. Its physical design and engineering allows a Marx generator to become incrementally bigger, without reaching a critical maximum dimension, as scientists seek more and more voltage to create higher and higher levels of radiation. While IP developed its sequence of FX machines during the 1960s, PI initiated design of its numbered Pulserad machines, paralleling the climb in achieved power. Frank Ford's research and development on Marx generator-produced pulsed power at PI led to the establishment of a pulsed power division there, and in the very early 1960s he completed work on the prototype for the first Pulserad machine soon on the market (Kerris 1995). The Pulserad 1150, operating at 4.5 MV, paralleled the HIFX (DNA 1984, 12-13; Agee 1996). In 1966-1967, PI built Hermes I, a Pulserad machine of 10-million volt power, for AEC's Sandia Base. J.C. Martin, assisting from AWRE, and Sandia's Thomas H. Martin (no relation to the British Martin), developed the technology for this simulator (Yonas 1978, 5). In 1968, at the same time as the IP setup of the FX 100 at the AFWL in Albuquerque, PI installed the Pulserad 1590 at the same installation. The Pulserad 1590 also achieved 10 MV of power. Through the parallel support of both the FX 100, with its Van de Graaff generator, and the Pulserad 1590, with its Marx generator, DASA and the AEC kept the broadest possible scientific base for their quickly accelerating need to have state-of-the-art radiation effects simulators. By the date of the Hermes I and Pulserad 1590 installations, work was in progress toward the magnitude-larger Aurora, itself a Pulserad machine. Smith had arrived at PI to work on achieving the leap from Hermes I/Pulserad 1590 to Aurora, soon joined by Philip D'Arcy Champney from AWRE as well. The immediate PI precursor to Aurora came with the 10.5-MV Pithon simulator, built like the Pulserad 1150 at the California PI facilities and still in use as a DNA-sponsored machine. Maxwell Laboratories, during research escalation toward the 1968 Aurora competition, designed and built its competitive simulator, the Blackjack 3, guided by Martin physicist Roger White (Caldwell 1996). The Blackjack 3 achieved about three-quarters of the maximum radiation dose attained by PI's Pithon, but did so with much lower current and voltage parameters (DNA 1984, 24-25). Maxwell's work with the Marx generator moved in a different direction after PI won the Aurora job, with major achievements in moderate bremsstrahlung machines designed for the Navy (Agee 1996).

The design and engineering of Aurora achieved a first plateau internationally for radiation effects machines. PI built a one-quarter version, with a single Marx generator and Blumlein system, at its Tracy, California, site, incorporating this equipment later into the installation of Aurora at Adelphi. Operational in 1972, the Aurora machine had no direct competitors for gamma ray simulation at its generated intensity until the design and setup of Hermes II in 1978-1979 at Sandia. DOE (formerly AEC) physicist Thomas H. Martin was again chiefly responsible for the technical advancements; Hermes II and Aurora were directly comparable simulators, although with technically differing power generation (Yonas 1978, 4-5, 10, *13; 5th Bi-annual IEEE [Institute of Electrical and Electronic Engineers] Pulsed Power Conference* 1985; Mikkelson, et al., ca. 1990). Scientists used Aurora to test components of Hermes II, further running experiments for a Hermes II Look Alike in 1984. In a sense, Aurora and Hermes II, and subsequently Hermes III, were collaborators (Aurora Test List 1992; Agee 1996). The magnitude jump from the FX 100 and 10-million volt Pulserad machines to Aurora is also symbolic of a parallel experimentation with pulsed power to artificially achieve fusion through the confined implosion of tiny pellets of deuterium and tritium. The goal was fusion ignition for the hydrogen bomb, itself a fusion device designed with a fission trigger (an atomic bomb). On the eve of Hermes II, scientists commented that, after three decades of attempts, no fusion trigger had been possible and that the work of J.C. Martin had been critical in the advancements achieved. In fact, from about 1960 forward, with the patent disclosure of A. John Gale of HVE (the parent company of IP), beam-driven inertial confinement fusion was under active consideration in the U.S., and, between 1964 and 1967, Frank Ford and his pulsed-power division at PI not only worked on scaling up pulsed power for radiation effects simulators, but also for an electron-beam accelerator usage to create artificial fusion. Physicist Ken Prestwich at Sandia developed the Proto I in 1974-1975 for contained fusion experiments. Thomas H. Martin directly complemented Prestwich's achievement, with design and development of Proto II in 1977-1978. Saturn followed in 1978-1979 (Yonas 1978, 12-13). Aurora's original technical parameters as an electron-beam accelerator were not suitable for fusion experiments; those of Hermes II, however, were (Yonas 1978). This alternate path for pulsed-power, partical beam fusion is a critical one to acknowledge (Smith 1991, 15). Quite possibly it had been present theoretically, in a classified capacity, from the initial years of work at Aldermaston toward development of the British hydrogen bomb in the middle 1950s under J.C. Martin.

In ca. 1982-1984, escalation toward a next plateau in radiation simulators began internationally. Responding to the state of U.S.-Soviet weapons development and to President Reagan's Strategic Defense Initiative (SDI or Star Wars), the pulsed-power physics community designed a variety of new machines, as well as making significant modifications and improvements to existing machines. The range of accommodated experiments widened. Radiation simulators sometimes handled complete systems, such as the Peacekeeper missile, in hardening tests. Electron beam and soft x-ray technologies reflected the continued concern with the fusion trigger and the relatively recent understanding of the x-ray's damaging role in space (Agee 1996; Caldwell 1996). PSI, the Ian Smith spinoff company from PI, designed Sandia's Hermes III in 1987-1988, with both indoor and outdoor cells for systems-simulated gamma radiation testing. Within the same laboratory infrastructure, are Sabre and Proto II, accelerators for particle beam fusion research. Sandia designed Proto II as a prototype particle beam fusion machine; PSI modified Proto II to accommodate additional use in soft x-ray and low-voltage bremsstrahlung effects testing. Hermes III, operating at 20 MV, with a pulse width of 21-28 nanoseconds (ns) and a rise time of 11 ns, supports other diode beam configurations, or front-end modifications, such as the pinched-beam mode to produce very intense radiation doses (Sandia National Laboratories 1989, 3-4, 24-30). At mid-decade, other new radiation simulators, all significantly smaller than either Aurora or Hermes II/III and built chiefly as moderate bremsstrahlung machines, included the Pulserad Little Mountain Facility of Hill AFB, Utah, for standardized hardening tests of Air Force equipment parts pulled out of stockpile (Kerris 1995; Caldwell 1996); the Double-Eagle at PI in San Leandro; and the Blackjack 5 at Maxwell Laboratories in San Diego (DNA 1984, 14-17). Internationally, the German flash x-ray facility at Munster, run by the Transient Effects Electronic Division headed by Dr. Walter Kornahl, also purchased a moderate bremsstrahlung simulator, operated at 6 MV with a pulse width of 80 ns, during the 1980s (Agee 1996). In the former Soviet Union, the I.V. Kurchatov Institute of Atomic Energy in Moscow planned to have an electron beam accelerator, comparable to Aurora in wattage and similar in design to Saturn, operational in 1984 for particle beam fusion experiments (Angara V) (Yonas 1978, 13).

Over the past 30 years, as many as 30 to 40 flash x-ray simulators have been built worldwide, exclusive of small prototypes and Febetrons. The successful line of radiation effects simulators evolved relatively quickly, powered by Marx generators and abandoning the Van de Graaff path. Within the Marx group, however, two distinct major variations occurred: (1) those with oil-insulated high-voltage capacitors and elongated oil-insulated capacitor pulse-forming lines (Blumleins); and (2) those with oil-insulated high-voltage capacitors and short, water-insulated capacitor pulse-forming lines. The oil-oil configuration, as at Aurora, is characterized by high voltage and moderate current: the higher the voltage, the higher the radiation dose produced. The oil-water configuration is characterized by moderate voltage and high current, which still can produce high radiation (Huttlin 1996). In the U.S., machine names are consistently overlaid with allusions to Greek and Roman mythology; birds and reptiles of great strength, longevity, or wisdom; and, for the Naval facilities, skilled risk-taking for high stakes (such as the Casino, Gamble, and Blackjack machines). Very few American radiation simulators were titled as prosaically as Febetron (field emission betatron), FX (flash x-ray), or Pulserad (pulsed radiation); these machines were essentially prototypical, stemming from the earliest research developments. Today, about 20 flash x-rays are operational, from those of small size to Hermes III (Kerris 1995). Currently in planning and development are Decade, a very high-intensity x-ray simulator, in test by the Navy and in construction by PI in Tennessee at Arnold AFB, following consideration of both the

Adelphi ARL site and WSMR, New Mexico (Kerris 1995; Poirier 1995; Caldwell 1996); and three DOE "large pieces of equipment that together would replace nuclear weapons tests by duplicating some conditions that exist in a nuclear explosion" (Wald 1996). With the decommissioning and dismantling of Aurora (with its capacitors shipped to Arnold AFB for Decade), only Hermes III is currently operational as a large-scale U.S. gamma ray simulation facility.

The Aurora Physicists and the Conducted Tests

The initial group of physicists and physics-technicians assembled at the Aurora Simulator between 1968 and 1975 included Paul Caldwell, Alexander Stewart, Robert Lamb, Dennis Whittaker, Al Poirier, Klaus Kerris, Stuart Graybill, and George Huttlin. Of these men, Caldwell, Stewart, Poirier, Kerris, and Huttlin participated in lengthy oral interviews during 1995 and 1996, both in person and by telephone, for the Historic American Engineering Record (HAER) documentation of Aurora. In addition, the second-era (1982-1990) leader of the Aurora facility, physicist Forrest (Jack) Agee, also participated in a substantive oral interview. Specific commentary from particular interviews is referenced throughout the text, with crediting to the scientists. Brief biographical summaries for each man are given below, focusing on academic training and work experience prior to arrival at Aurora. All individuals were highly cooperative, contributing immeasurably to the HAER project.

At a future date, supplementary telephone contacts are recommended with PI physicist Bernie Bernstein (coauthor of the lead documentation article on Aurora; oil-oil versus oil-water insulation systems; discussion of the Decade project); NRL physicist Jerry Cooperstein (contextual discussion of the Navy radiation effects simulators and current Navy plans relevant to the decommissioning of Aurora); retired physicist J.C. Martin (head of the Aldermaston radiation effects unit from 1947; consultant for Aurora and Hermes I); Ken Preswitch, retired Sandia physicist (Hermes simulators in relationship to Aurora); PSI physicist Ian Smith (designer of the Aurora Simulator and colleague of Martin at Aldermaston); Ed Walsh of C-LEC Plastics (discussion of the critical plastic rings manufactured for HIFX, Aurora, and Hermes II and III; lack of a parallel supplier for the former Soviet Union); Maxwell Laboratories physicist Roger White (contextual discussion of the Maxwell competition with PI for the Aurora commission; Maxwell simulators; training and work with Martin at Aldermaston); retired physicist Frank Winenitz (international context of the French, German, and Soviet simulators); and physicist Nino R. Pereira of Berkeley Research Associates (Soviet simulators; 1980s-1990s work to develop Aurora's capabilities, inclusive of microwave, source-region electromagnetic pulse [SREMP] simulation, and the new Marx generator). The interviewed Aurora physicists have strongly suggested contact with each of these individuals and will provide telephone numbers. Additionally, the Aurora physicists have offered to write a technical appendix on the Aurora Simulator, addressing the specialized parameters of its testing capabilities and providing a fuller context of U.S. and international simulator history.

The Physicists

Forrest (Jack) Agee: Now at the USAF Phillips Laboratory, Kirtland AFB, Albuquerque, New Mexico, Dr. Agee completed his graduate work in low temperature physics at the University of Virginia. His first work experience was in superconductivity and superfluidity for the U.S. Army at Fort Belvoir, Virginia. In 1971 he decided to concentrate on applied physics rather than research, specializing in electro-magnetic pulse (EMP). Dr. Agee worked at the Army EMP facilities at Woodbridge, Virginia, under the jurisdiction of the Army Materiel Command (AMC), 1971-1977, reporting on a field test conducted in Hawaii (1977) during 1978. Between 1979 and 1981, Dr. Agee worked in the private sector. In 1982, he hired as the branch chief for the Aurora Simulator at HDL. During his tenure at Aurora, he supervised all the major facility modifications of the 1980s for the Reagan Cold War buildup, in addition, bringing a high-level of business acumen and efficiency to his mission. After his leadership of Aurora, Dr. Agee continued at HDL in the high-power microwave program for three years before hiring at the Phillips Laboratory (Agee 1996).

Paul Caldwell: Physicist Caldwell graduated with a B.A. in physics from the University of Minnesota in 1942. During his undergraduate years he worked on the assay of uranium using mass-spectrometers for the Manhattan Project's facilities at Oak Ridge, Tennessee. Following degree completion, Mr. Caldwell hired with the Centimeter Wave Research Branch of the NRL in Washington, D.C., and during the remainder of the war worked with radar jammers. In ca. 1946, he moved to the Physics, subsequently Nucleonics, Division of the microwave group at NRL, working in thermal diffusion and the separation of uranium using mass-spectrometers in the analysis. In 1954, a fellow physicist asked Mr. Caldwell to join him in the hydrogen bomb tests on the Bikini Islands, to measure the attenuation of radio waves of differing frequency from the fireball in order to attain data needed for the planned high-altitude tests of the later 1950s. He participated in the Yucca, Teak, and Orange tests at Johnson Island in 1958, measuring nuclear radiation for DASA. In about 1960, Mr. Caldwell joined HDL, participating in atmospheric and underground nuclear trials at the Nevada Test Site, inclusive of Small Boy in July 1962 and Milkshake. In addition, he was directly responsible for contracting the development of HIFX, 1962-1964, and Aurora in 1966-1968. Mr. Caldwell headed the Aurora Simulator from 1968-1979/1980, when he partially retired and began compiling a database on nuclear testing for Command Sciences, a research company directly responsive to DNA. Mr. Caldwell is now fully retired. He maintains a close personal and professional relationship with J.C. Martin at Aldermaston ("Aurora Facility" 1972, 24-25; Kerris 1995; Caldwell 1996).

George *Huttlin:* Dr. Huttlin completed a B.A. in physics at La Salle College (University) in Philadelphia in 1969. He subsequently undertook a Ph.D. in physics at Notre Dame University, with dissertation defense in November 1974. In the beginning of January 1975, Dr. Huttlin hired with the Aurora Simulator at HDL, formally completing his Ph.D. the same year. Dr. Huttlin's physics expertise has most recently focused upon research on high power microwaves. He was the final physicist hired to be a part of the original Aurora group, and the only one recruited directly following university training. Dr. Huttlin has spent his career to date contributing to work at Aurora (Huttlin 1995, 1996).

Klaus Kerris: Physicist Kerris began his academic years at Ohio State University, transferring to the University of California at Los Angeles (UCLA) and completing a B.A. in physics in 1957. Continuing his graduate studies at UCLA, Mr. Kerris completed his M.A. in physics in 1959 and one year toward a Ph.D. in 1960. While at UCLA, he worked as a research assistant in the cyclotron laboratory under Dr. Kenneth R. McKenzie. There he participated in the design and building of the UCLA 50-MeV cyclotron, a proton accelerator; Professors McKenzie and Wright were then moonlighting in such work for Pomona College, one of the Claremont Colleges in the region. Work in the cyclotron laboratory also brought Mr. Kerris into contact with Hughes Aircraft Corporation, again through the design and building of a small cyclotron. Hughes hired Mr. Kerris in the summer of 1960. At that time, Hughes, like other major military contractors, had established a Nucleonics Division, then running projects in three areas of potential commercial expansion: Mobots (mobile-robots) and robotic gadgets designed to function in hazardous areas, like those immediate to nuclear reactors; accelerators; and nuclear radiation effects. Tom Hanscome, a former colleague of Paul Caldwell at the University of Minnesota and the NRL, headed the radiation effects unit. Mr. Kerris chiefly designed radio-frequency electron-source linear accelerators (RF Linacs), patterned after the Linac at Stanford University, while at Hughes. The U.S. Army radiation effects test center at WSMR bought the first Hughes Linac for radiation effects testing; a second Hughes Linac was very successfully used for 20 years in the Hughes radiation effects research program. However, efforts to develop a commercial market for Hughes Linacs was a failure. Nonetheless, Hughes Aircraft Corporation, Northrop, Boeing, and HDL were all ground-breakers in the earliest American radiation effects work. Some early leaders, such as Northrop, used reactors to produce neutron environments for radiation effects research. It was soon realized, however, that neither the Linac nor the Triga could create the intense energy and very short pulse needed in the radiation effects business, and American scientific research shifted to flash x-rays and the British technology of field emission radiography developed by J.C. Martin. Hughes Aircraft Corporation almost immediately decided that neither Mobots nor Linacs would remain viable enterprises, but the company did continue to support Hanscome's nuclear radiation effects work (which was funded heavily by DNA). Paul Caldwell then went to Hughes to request a Hughes experimental group to assist in tests at the Nevada Test Site; Mr. Kerris worked directly with Mr. Caldwell in Nevada. By 1970, Hughes' research and development unit under Mr. Hanscome had dropped from its high of about 50 individuals to only 11, and it looked as if the effects business there was phasing out. Paul Caldwell hired Mr. Kerris as a physicist for the Aurora Simulator on August 2, 1971, with focused expertise in dosimetry. During 1981-1982, Mr. Kerris acted as interim branch chief at the Aurora Simulator, prior to the hiring of Dr. Agee. He continues to be with Aurora today. His primary duties are managing ARL's program to enhance the protection of combat vehicle crews against initial nuclear radiation in tactical battlefield environments (Kerris 1995).

Al Poirier: Physics-technician Al Poirier first worked at HVE in Burlington, Massachusetts, near Boston, joining the company in 1955 following completion of his A.A. In 1962, after the IP spin-off from HVE, Mr. Poirier followed his mentor at HVE, physicist John Paul Shannon. Mr. Shannon worked directly with Alexander Stewart on the design of the FX 45 and on the HIFX, commissioned by Paul Caldwell specifically for HDL. Mr. Poirier continued work on the FX series of machines for IP from 1962-1968. At its peak, IP employed about 180 individuals, climbing from its initial size of 25-30. In 1969 Mr. Poirier went to Kirtland AFB, in Albuquerque, New Mexico, to handle the service contract on Ares, a large EMP cable-system simulator installed by IP for the Air Force. Maxwell Laboratories had won the service work on Ares, and Mr. Shannon had hired with Maxwell in San Diego in 1968, working there until his death from cancer in 1989. After two-and-one-half years at Kirtland AFB, Mr. Poirier arrived at Aurora on June 26, 1971. Mr. Poirier retired in September 1996, with the formal closure of the Aurora Simulator, after 25 years of service at Adelphi. Mr. Poirier has recently worked with Mr. Kerris on the installation of the Decade simulator equipment in Tennessee (Poirier 1995, 1996).

Alexander Stewart: Physicist Stewart graduated from the University of Strathclyde, Glasgow, Scotland, with a B.S. in 1953. He joined J.C. Martin's group at Aldermaston in 1959, working on unconventional means of generating pulsed power and continuing graduate studies in physics. In 1962, after Paul Caldwell had conferred with Martin regarding the need for American radiation effects simulators paralleling the power of those at Aldermaston, Mr. Stewart immigrated to the U.S., hiring with IP to develop the HIFX installed for HDL in 1964. Mr. Stewart won the Industrial Research 100 Award for the HIFX. IP sold the FX 45, the generic version of HIFX, to about six customers, inclusive of military representatives of the French and Swedish governments. During 1963-1964, while Mr. Stewart was at IP, the company also received visits from Soviet representatives. DASA allowed Mr. Stewart to present a paper on HIFX, placing selected information in the public domain, and, in effect, making the HIFX technology a form of intimidation focused toward the Soviets. When DASA seriously escalated its search for a more powerful radiation effects simulator during 1965-1967, the American pulsed-power community understood the upcoming request for proposal to be aimed at the two companies with the Marx generator technology, which was interpreted as the most probable for success in a large simulator. To be near those companies, Maxwell and PI, in Southern and Northern California, respectively, Mr. Stewart moved to California, taking a job with Philco-Ford in the Bay Area (nearer PI). Simultaneously, Ian Smith, J.C. Martin's brightest protégé in pulsed-power simulator research and development, hired with PI. In 1967, before the Aurora contract was awarded, Mr. Stewart approached Paul Caldwell of HDL, with whom he had worked closely on HIFX, about the possibility of directing the specifics of the imminent program planned for radiation effects simulation and weapons testing. In 1968, after DASA awarded PI the Aurora contract, Mr. Stewart hired with HDL to develop the program as he had offered. Working with Aldermaston's Martin, and PI's Smith, formerly of Aldermaston, Mr. Stewart followed the assignment of Mr. Caldwell to the Aurora project. Mr. Caldwell and Mr. Stewart then hired the first core group of physicists and physics-technicians for the Aurora Simulator. Mr. Stewart continued in this association with Aurora until 1982, when he undertook a different assignment at HDL. He continues at ARL (the successor of HDL) today (Stewart 1995; Kerris 1995).

The Tests

Between April 1972 and September 1995, 287 numbered tests occurred at the Aurora Simulator. In addition, PI ran experiments during 1978-1979 for the Aurora Modification Project (AMP), a project to deliver the energy stored in the capacitors of the Marx at a lower voltage and higher current through an appended water-insulated pulse generator built parallel to the Marx tank. (Subsequently dismantled, the AMP equipment at Aurora was reassembled at the NSWC as the PI simulator Phoenix.) The total 288 tests generated somewhat in excess of 10,000 test shots. Of these, 9,100+ shots resulted from the 287 numbered tests; PI ran approximately 1,000 shots for the single 1978-1979 AMP test ("The Aurora Gamma Ray Simulator" 1995; Huttlin 1996).

When DASA contracted for Aurora, the explicit mission of the simulator focused on testing the electronic packages atop missiles, first ABMs and then ICBMs, for their sustained hardness under conditions present in the gamma radiation environment created with a nuclear detonation. Thus, the physical design and engineering configuration of the Aurora Simulator are directly reflective of three factors: (1) the intended packages to be tested and refined (most immediately, ABMs); (2) what type of nuclear detonation was anticipated and where it would occur (low-level atmospheric nuclear explosion, with substantial damage projected from the effect of gamma radiation); and (3) the state-of-the-art or the nuclear effects business (what was understood to be true and what was still not known about the physics of nuclear detonations). Planned test packages were still small and, not surprisingly, so was the Aurora access door. Additionally, the technology of the electronic guidance systems then in design for ABMs and ICBMs defined the needed parameters of the simulator-generated bremsstrahlung pulse width; in relative terms, the pulse width required was long, 150-160 ns. Designed to test against simulated gamma x-rays, the Aurora Simulator also needed to produce intense radiation and was engineered to do so through high voltage and moderate current. These parameters, combined together with what physicists were technically able to do in ca. 1967-1970, made the Aurora machine physically large due to the size of its Marx tank (with the number of contained capacitors) and the length of its oil-insulated (moderate current condition) Blumleins. Its pulse width meant the rise time of the simulator was also relatively long, with both pulse width and rise time subject to only limited future modifications. Finally, the focus on the simulation of gamma radiation, without an understanding of the very different future needs of the soft x-ray environment of space, for instance, defined what would become the scientific life span of the machine (Huttlin 1995, 1996; Agee 1996; Caldwell 1996).

Tests run in the first years of Aurora concentrated on those for the Spartan and Sprint ABMs, set up by military contractors and sponsored almost exclusively by commands within the Air Force. As early as late 1972, however, DNA began using Aurora for methodology testing, inclusive of EMP experiments, field sensor tests, radiation effects testing on fluidics, experiments for the cesium frequency standard for Global Positioning System (GPS) technology, and tests on a material response to electron beams. Both the NRL and Wright-Patterson AFB (WPAFB) used the Aurora Simulator by 1973; NRL tested a satellite on-board processor, and WPAFB tested a hardened solar power system. Beginning in late 1974 into the autumn of 1976, strengthening at the end of the decade, the AMC, partially through its then-named Electronics Command (ECOM), tested some of its future battlefield electronics and equipment, inclusive of the forward area teletype, the ATAC-45 trailer, the XM-735 and XM-75 fuses, a laser rangefinder, communications gear, and a biological detector-warning system. The Army testing in the middle 1970s is evocative of a perceived American-Soviet Union Cold War parity and of a U.S. strategic shift, from theories that any nuclear confrontation would chiefly, if not entirely, be a missile exchange, to theories that nuclear war would first involve a conventional ground war, then a nuclear air exchange, and conclude with sustained ground efforts (Agee 1996). Military contractors using Aurora included McDonnell Douglas, BTL, Honeywell, Hughes Aircraft, TRW, RCA, Northrop, General Electric, Aerojet, Raytheon, Bendix, and Rockwell. By 1979, the Navy tested packages for the Trident missile; Hill AFB tested hardness for VHF (very high frequency) transmitters and ERSC power supply.

During the 1980s, DNA, chiefly through HDL and sometimes through a joint HDL-NRL effort, ran more methodology-oriented tests, such as ones experimenting with aspects of ion diodes, positive polarity, and electron beams. The 1980s also witnessed the shift to a need to test whole systems, with the MX-Peacekeeper ICBM experiments appearing continuously through 1992. In mid-decade, the modifications to Aurora accommodated shifting needs to test in other than a simulated gamma radiation environment and by 1989 were partially intended to parallel testing possible at Hermes III at Sandia. The soft x-ray environment of deep space, important to SDI (Star Wars), and the requirement to test whole satellite systems led to the Aurora experiments named Flubber. Flubber, and its identified Flubber cart (for use in the test cell), was one of the only truly whimsical touches at the Aurora Simulator. The name, taken from an early 1960s Walt Disney movie *(The Absent Minded Professor)* about a lovable, out-of-touch scientist who created a substance that simulated the weightlessness of space, referenced technical modifications made to accommodate satellite soft x-ray testing at Aurora. (The other subtle levity was the placement of a small stuffed dog wearing a plaid tartan, high in the corner of the test cell. Overlooking the irradiation, the dog was never noticed by Scottish physicist Alexander Stewart, whom the dog is thought to represent.) Finally, the later 1980s saw two of the Aurora physicists, George Huttlin and George Merkel, run extended methodology experiments focused on high power microwaves (an SDI need) and source-region EMP (SREMP) (an Army battlefield need), respectively. Late-era military contractors using Aurora included Lockheed (Trident II), Textron (Peacekeeper), IIT (communications devices), Martin Marietta (the Lance anti-tank missile system), and Texas Instruments (thermoelectric coolers). The Army sponsored the final tests run at Aurora in September 1995 for an ion diode project, PORTS (Aurora Test List 1992; Poirier 1995, 1996).

Soviet Counterpoint

To date, Soviet advancements in nuclear radiation effects testing for Cold War weapons development, 1945-1995, is not widely discussed, documented, or understood, although certainly experts on the capabilities of the former Soviet Union exist. In particular, in the U.S. Ihor Vitkovitsky, of Logicon RDA, Arlington, Virginia, and Magne Kristiansen, of the Electrical Engineering Department, Texas Tech University, Lubbock, are knowledgeable. Nonetheless, interactions between the Aurora physicists and their international colleagues, as well as the reflections of the Aurora group following the visit several years ago by a pair of Soviet scientists to the Adelphi facility, suggest that professional opinions about the Soviet state-of-the-art, *during* and *at the close of* the Cold War, vary widely. Military security, of course, further suggests that it was inappropriate to talk about any known Soviet counterpoint during the Cold War itself, and such long-sustained silence may enter into a reticence to voice knowledge yet today. Published sources, however, from as early as ones in the 1975-1978 issues of *Physics Today* and *Scientific American* to David Holloway's 1994 *Stalin and the Bomb*, definitively point to the likelihood of substantial Soviet accomplishments paralleling those of the British and the Americans in radiation effects simulation.

The former Soviet Union possessed some of the world's best twentieth century physicists, with international leaders active during the research-laden 1930s and the dawn of the nuclear era. After the Bolshevik revolution, the new Communist regime had encouraged closer ties between science and industry, and had established new research institutes in the late 1910s and 1920s (Holloway 1994, 10-15). Dr. Iulii Borisovich Khariton, educated at the Leningrad Polytechnic Institute (earlier known as the State Physicotechnical X-ray Institute) and in receipt of a Ph.D. from Cambridge in the late 1920s, headed a 1930s-created laboratory at the Leningrad Institute of Chemical Physics to study explosives. During 1939-1941, he conducted significant research experiments on nuclear chain reactions with another Soviet physicist, Iakov Borisovich Zel'dovich. Early in World War II, in the spring of 1943, the former Soviet Union formally decided to undertake a nuclear project, setting up a secret laboratory in Moscow, named Laboratory No. 2. Igor Vasil'evich Kurchatov, the Soviet Union's preeminent nuclear physicist, headed the atomic project and Laboratory No. 2 until his death in 1960. Laboratory No. 2 was henceforth named the Kurchatov Institute and continues in existence today. Directed by, and working with, Dr. Kurchatov were both Khariton and Zel'dovich at the Moscow secret facility (Holloway 1994, 96ff).

In June 1945, before the July 16th detonation of the Trinity atomic bomb in New Mexico, and before the August 6th and 9th droppings on Japan, Dr. Kurchatov decided to begin large-scale laboratory experimentation with the implosion method associated with the atomic bomb, using high explosives. Laboratory No. 2 was sited on the then-outskirts of Moscow, but was too near a major population density to serve as the location of Kurchatov's planned project. After the events ending World War II, motivations for Kurchatov's new laboratory became emphatic. Dr. Kurchatov set up a branch of Laboratory No. 2, that is a branch of the later-named Kurchatov Institute, at Sarov, 400 kilometers to the east of Moscow. Kurchatov appointed Khariton to be the chief designer and scientific director, with a military administrative head. The first site visit to Sarov occurred in April 1946. Sarov contained both a small munitions factory that had been in use during the war for rocket artillery manufacture and the remains of an Orthodox monastery from the eighteenth and nineteenth centuries, closed by the Communists in 1927. Its siting made massive expansion possible; its remoteness promised security; and its beauty would attract the type of captive intellectual residents sought. Khariton set up his first test laboratories in the derelict cells of the more than 300 monks once living at Sarov. Gulag labor then built a huge new complex of nuclear laboratories and houses, a scale of endeavor paralleling those at Aldermaston and at Los Alamos. What began as a branch laboratory received the formal name of KB-11 (konstruktorskoe biuro-11), soon replaced by Arzamas-16 (after the city of Arzamas, 60 kilometers to the north of the Sarov site). It was also soon nicknamed "the Volga office" and "Los Arzamas," with a later Soviet title of the All-Union Research Institute of Experimental Physics (Holloway 1994, 196-200, 437). (All Soviet nuclear laboratories and manufactories were given numbered site names, for example, Cheliabinsk-70 [a second weapons design laboratory of ca. 1955, later named the All-Union Research Institute of Technical Physics], Tomsk-7, and Krasnoiarsk-26 [plutonium manufactories]). What is notable here is that even though American temporary facilities had been sited in New Mexico since 1943, expanded, permanent Cold War construction at the American Los Alamos and the Soviet Arzamas-16 was almost simultaneous in the spring of 1946, immediate to the world foreshadowed by the Hiroshima and Nagasaki detonations (Hewlett and

Anderson 1962, 229ff, 630-31). British permanent facilities at Aldermaston lagged behind the U.S. and Soviet Union by about four years, in part due to the long negotiations through 1949, directly inclusive of Dr. Penney, for combined British-American research, production, and infrastructure (Hewlett and Duncan 1972 reprint of 1969, 309-10). Each of the American, British, and Soviet atomic facilities expanded dramatically during the 1950s.

The Soviet approach to the business of nuclear effects simulation is also of significant early parallel. Dr. Khariton recruited among his very first physicists, V.A. Tsukerman. Dr. Tsukerman worked at the Institute for the Study of Machines. There, with the aid of his wife Z.M. Azarkh, he had experimented using x-rays to study the details of how artillery shells behaved when penetrating armor. A diagnostician who was additionally blind, Tsukerman was using flash radiography. Dr. Khariton had noted during late World War II how the radiographic techniques could be applied to the analysis of a nuclear detonation, specifically how it could be employed to study the implosion of the plutonium pit. At Arzamas-16, Dr. Tsukerman "devised a system that used microsecond X-ray pulses to map the high-speed detonation processes and to analyze the implosion of iron, bronze, and other metals" (Fleischmann 1975, 35; Holloway 1994, 198). Khariton invited Tsukerman to Arzamas-16 in December 1945. By at least the close of 1946, Tsukerman and his wife Azarkh had their own laboratory at Arzamas-16, with scientists and engineers still arriving. A cooperative idealism pervaded Arzamas-16 among the scientists, working under highly unusual conditions for the Soviet Union, generally; pay was high, housing was excellent, and food and goods were exceptional. While post-war conditions in Moscow were abysmal, those at Arzamas-16 were elitely futuristic, with the Soviet atomic facilities described by one of Tsukerman's researchers as a "white archipelago" identical in its secured isolated zones to the gulag archipelago of the forced-labor camps (Holloway 1994, 198-204). William Penney's work at Los Alamos on effects in 1944-1945 and at the Bikini tests in 1946 overlaps the Soviet endeavors, as does the British setting up of HER in 1946-1947. Dr. Penney, however, did not recruit J.C. Martin until September 1947, 22 months after Khariton had similarly recruited Tsukerman. The U.S. had no parallel physicist teams to Penney-Martin or Khariton-Tsukerman pursuing simulated radiation effects for weapons laboratory testing, derivative from radiography, until the 1960s; in that era, American work was closely advised by Martin. Dr. Thomas H. Martin, of Sandia, is perhaps the American physicist most closely affiliated with sustained flash x-ray simulator design, helped in his first efforts for Hermes I by J.C. Martin.

Thus, at the outset of the Cold War the Soviets' work in radiography and laboratory effects exploration and its correlation to nuclear bomb-making were strikingly parallel. Just like the U.S., the Soviets developed large radiation effects simulators during the ca. 1960-1990 period; flash x-ray radiography was certainly used for weapons testing. As designed laboratory machines became more sophisticated, and as knowledge increased on the physics of electron beam behavior, wider usages of pulsed power technology came to the fore, in particular the adaptation of electron-beam accelerators for the creation of thermonuclear fusion. Both the U.S. and the former Soviet Union clearly documented their interest, and progress, in the design of pulsed-power machines for particle beam fusion experimentation. Leonid A. Rudakov led the Soviet electron beam program in the late 1970s, at that time commenting that scientist E.A. Zavoiski at the Kurchatov Institute in Moscow had decided in 1968 to seriously pursue the scaling up of the basic radiographic technology, with a formal proposal to do so appearing in 1971 (Yonas 1978, 6). The 1968-1971 time frame is comparable to that for the achievements of Hermes I and Aurora. By 1975, Cornell University physicist Hans H. Fleischmann referenced the existence of Soviet machine technology, using dehydrated glycerine as insulation for the required high-voltage transmission and juxtaposing this solution to the American use of oil and deionized water. In 1978, physicist Gerold Yonas, first trained at Cornell, and subsequently working at PI before becoming the manager of the fusion-research program at Sandia, further noted cutting-edge power concentration solutions achieved by PI, the Kurchatov Institute, and Sandia (Fleischmann 1975, 36; Yonas 1978, 9). Finally, Dr. Yonas commented in 1978 that Saturn, then under construction at Sandia, was planned for upgrading to accommodate particle-beam fusion experimentation, in addition to its radiation effects testing capabilities, by 1985. Simultaneously, Dr. Yonas noted that the Kurchatov Institute was then developing the Angara V accelerator, a $50 million machine of 10 terawatts peak power that would support particle-beam fusion experimentation by 1984 (Yonas 1978, 13). However, Angara V's peak power to be achieved by 1984 did not exceed Aurora's, the latter having been available more than a decade earlier. In addition, Angara V, as-built, most directly paralleled the Proto II and Saturn accelerators, both designed for Sandia in the late 1970s (Yonas 1978, 12-13; Sandia National Laboratories 1989, 19-23, 28-29).

Conclusions from these factual fragments, regarding the state of the art for Soviet radiation effects simulator development paralleling that leading to, and from, Aurora are several. At a basic level, Soviet scientists pursued the radiographic technology they possessed in 1945 forward into the field of effects simulation and weapons testing, naming and numbering a series of machines similar to the process for Hermes I-III and suggestive of four smaller versions of the Angara. From the information available in 1975 and 1978, it is likely that the Kurchatov physicists were about a decade behind in the art of achieving the design for a large electron beam accelerator (1978 versus 1969), but they had significantly achieved the intent, and possibly much of the theoretical technology, nearly simultaneously with the U.S. (1967-1968). As it turns out, Angara V was only partially successful and, in its original concept, remains unfinished to this day (Pereira 1996). Three of the six interviewed physicists at the Aurora Simulator commented on a Soviet visit of two scientists to the facility ca. 1989-1991. Dr. Agee noted that the inspection by the former Soviet senior physicists included both Aurora and Sandia and that it complemented a parallel inspection by American scientists to the former Soviet facilities. Dr. Agee described the Soviet efforts at building an Aurora-comparable simulator as unsuccessful; he stated that the Soviets had started to build a parallel level of machine, but had been unable to finish the project. Physicist Stewart also commented that the Aurora technology existed "here, but not there [in the former Soviet Union]" (Stewart 1995). Physicists Huttlin and Kerris both corroborated Agee and Stewart, and all four pointed to a specific reason for the Soviet failure; the Soviets had been unable to manufacture the large plastic insulator rings required by the technology of the machines. Only a single small company had made these in the U.S., C-LEC Plastics in Philadelphia, creating the needed oversized pieces of very pure plastic. C-LEC made the rings for HIFX, Aurora, Hermes II, and Hermes III. Dr. Huttlin paraphrased his memory of the Soviet visitors' comments, noting that they had remarked that there had been only two causes for heartburn in their lives, Aurora and Hermes III (Huttlin 1995). Mr. Kerris added that members of a large Soviet delegation, just several years ago, had described the Aurora Simulator as a dinosaur; he had wondered whether they had been referring to the simulator's physical size and thus were reflecting further on what they had not been able to achieve, or whether it was a subtle double-edged comment, alluding to their success afterall and to the scientific antiquity of the Aurora technology by contemporary standards (Kerris 1995).

II. ARCHITECTURAL INFORMATION

A monolithic reinforced-concrete structure, two 800,000-gallon steel tanks, and a 7,000-ton gamma ray effects machine historically defined the 40,000-square-foot Aurora facility. Described in its September 1969 drawings as the "U.S. Naval Ordnance Laboratory, White Oak, Maryland, Gamma Ray Facility," Aurora featured a site plan with area-entry sentry post; secondary security gate; security fencing surrounding the facility itself, inclusive of 20-vehicle parking; and immediately outside the fenced area, between the sentry post and the Aurora gate, two planned adjunct facilities. These structures, a flash x-ray laboratory, and a pole-test facility were not constructed as first planned. HDL built the flash x-ray laboratory immediately across from the Aurora Simulator to the west. The flash x-ray laboratory housed HIFX (generating 4.5 MV of electricity), installed at the HDL Connecticut Avenue, Washington, D.C., site in 1964 and moved to the Aurora location post-1970. The pole-test facility remained unbuilt.

Infrastructure

The main components of the Aurora Simulator reinforced-concrete structure include the machine bay, the pump room, the insulating oil tank pit, the cave (alternately described as the simulator room), the underground test cell, the staging area and the mechanical equipment spaces, the data and control rooms, the security vault, and the laboratory and office wing. The structure uniformly rests on a reinforced-concrete double-slab foundation, with a waterproof membrane placed between the lower 4-inch and upper 5-, 6-, and 8-inch individual slabs. Additional reinforced-concrete foundation piers, pads, and railtrack support augment the foundation system. Roofing is predominantly open steel truss with insulated metal decking above covered with built-up sheathing; specialty areas of the structure are roofed-in reinforced-concrete and steel beams cast in reinforced concrete. Aesthetically, the primary design problem of the structure, the direct combination of oversized high-bay, single-story, and underground components, is solved through the application of continuous horizontal bush-hammered precast concrete panels, banded across full facades regardless of the height of individual building components. Of 8-foot width, the bands delineate the upper edge and lower one-third of the high-bay component, with the lower band continuing along the upper edge of the single-story office and laboratories wing. Alternate exterior reinforced-concrete surfaces are smooth finished and unpainted. The primary engineering problem at Aurora focused on establishing the appropriate radiation shielding and interrelated nuclear effects testing spaces.

The machine bay is the largest component of the structure, containing the Aurora simulation equipment and defining the building. Measuring 203 feet, 10 inches, by 107 feet, 7 inches, inclusive of wall thicknesses, the machine bay is of 67-foot, 8-inch height from the simulator floor to the top of the parapet and has an interior floor elevation of 180.5 feet. The interior space is designed as of five-unit width, with each unit approximately 21 feet, and of 10-unit length, with each unit 20 feet, 3 inches; units are delineated by foundation piers at the walls. The walls of the machine bay are 1 foot, 6 inches thick, with minor variations. The bay is at grade on the south facade, with the exception of a minor 5-foot elevation of earthen shielding west-to-east at the southeastern corner; on the west, the bay is shielded with an ascending 23 feet of earthen berm, south-to-north. Other building units of the Aurora Simulator abut the machine bay on its northern and eastern facades. Reinforced-concrete flooring is of specialized iron-armoured type within the space. Beneath the eastern half of the bay, two parallel reinforced-concrete track footings of 4- to 6-foot thickness, and running the length of the room, support rails for movement and placement of the simulator during tests and maintenance, additionally supporting the flooring. Beneath the western half of the bay, six concrete piers support the double slab (8 inches/4 inches) flooring. Seven floor drains and two vent stacks further articulate the space. In the southwestern corner of the bay, a reinforced-concrete loading dock, with a 20-foot wide ramp and 32-foot roll-up door, accents the facility. In the northwestern corner, a steel stair climbs to the laboratory hallway, with two steel-plated lead-core doors at its intermediate landing and at the top entrance/exit. Four hose reels, a wet sprinkler system, six foam nozzles (three manually operated), and a C02 alarm system provide additional built-in safety features. Roofing is of open steel truss type, of 5-foot vertical dimension, with metal decking and built-up sheathing above.

The pump room immediately abuts the machine bay on its eastern facade, near the bay's northeastern corner, and inside the insulating oil tank pit. Measuring 19 feet by 51 feet and of 11-foot height, the room has exterior walls of 1-foot thickness. The pumping system transferred the insulating oil from the storage tanks in the pit to the Marx generator tank in about one-and-one-half hours, as designed and initially operated (Bernstein and Smith 1973, 297).

The tank pit, open above and defined by its reinforced-concrete retaining walls, abuts the machine bay along its eastern facade and is completely shielded by an earthen berm. Measuring 156 feet north to south, and of 111-foot width, the pit features walls of 1-foot thickness. Its sloped eastern wall ascends in height from about 22 feet at the south to 28 feet at the north. The southern wall is 22 feet high; the northern wall is 27 feet. The shielding berms descend to about 10 feet below the top of the south and north walls, with their western corners abutting the machine bay. Two steel tanks of 59-foot diameter and 40-foot height sit inside the pit on 1-foot thick reinforced-concrete ring footings. The upper reinforced-concrete slab flooring of the tank pit is of 6-inch thickness. Insulating oil for the Aurora Simulator's Marx generator tank, itself permanently sited in the machine bay, was stored in the two tanks while Aurora was open for access.

The Aurora cave occupies the area between the north end of the machine bay and the south end of the underground test cell, serving both as an extension of the machine bay and as an anteroom for the test cell. The Aurora Simulator is positioned forward approximately halfway into the cave on its rail tracking, with the four angled x-ray transmission tubes carrying the electron beams from the four parallel Blumlein pulse-forming networks to the tantalum anode converter. The tantalum converter stops the electron beams, creating the machine's characteristic bremsstrahlung. Bremsstrahlung is projected further forward through the radiation window of the cave into the test cell. As an anteroom to the test cell, the cave is heavily shielded for radiation leakage. Its eastern facade is comprised of a 30-foot, 8-inch by 10-foot, 8-inch earth-filled cell, encased by 1-foot, 4-inch reinforced-concrete walls and built into the site 29-35 feet below grade. The western facade, shielding the control room, laboratories, and the office wing from the cave's potential radiation, is comprised of a reinforced-concrete wall of 8-foot by 30-foot, 8-inch dimensions, with additional concrete at the angled northwestern corner. The final wall of the space, joining it with the test cell to the south, is of 3-foot by 60-foot dimensions. Flooring is continuous with the machine bay. Roofing is 2 feet thick, comprised of steel beams in reinforced concrete. The height of the cave, stepped down from the machine bay at the roofline, is 58 feet, 6 inches; the elevation of the floor slab remains constant with that of the machine bay, with the exception of the north-end surface which slopes to the corners to accommodate draining. A reinforced-concrete exhaust shaft exits the cave into the earthen covering above the test cell, turning at right angles and continuing into the atmosphere.

The test cell is built into the site and is described as underground. Measuring 66 feet by 48 feet and of 16-foot, 8-inch interior height, the cell is heavily radiation shielded. Interior floor elevation is 203 feet, a rise of 22.5 feet from the interior floor elevations of the machine bay and the cave. On both the east and west facades, 7-foot, 10-inch wide earth-filled cells, enclosed in 1-foot, 6-inch reinforced-concrete walls, vertically encase the test area to a height of about 3.25 feet above the roof slab. The outer walls of each of the bracketing cells extend further upwards, narrowing to 1-foot thickness and defining parapets of about 6-foot above-grade height. The eastern parapet is extended horizontally as a reinforced-concrete canopy of approximately 52-foot length and 10-foot width to accommodate contractor data-equipment trailer parking. The 1-foot, 4-inch walls of the north test cell elevation were originally shielded by a sloped earthen berm descending from an elevation of 225 feet at the test cell (3 to 4 feet above the test cell roof) to 203 feet at the perimeter roadway of the Aurora Simulator site (interior test cell floor elevation), a distance of approximately 95 feet. To accommodate the nuclear effects testing of large systems, in the middle 1980s the Army altered the north facade of the test cell through the addition of a 15-foot wide by 8-foot, 7-inch high opening, shielded by a radiation door of approximately 3-foot thickness. An access drive into the test cell from the site perimeter road, bracketed by retaining walls, now bisects the original northern shielding berm. The south facade joins the cave. A 2-foot reinforced-concrete slab roof, entirely covered by 3-to-4 feet of earth, shields the test cell from above. Paralleling systems devised for long-distance electrical power transmission, the double-slab test cell flooring is specialized to allow continued generation of power during natural electrical disturbances such as thunderstorms. A counterpoise system of encircling copper bars, each of 5/8-inch diameter and of 5-foot depth, is embedded through the combined 10-inch thick reinforced-concrete floor slabs into the earth below. Stranded copper radiates in a closely spaced pattern from the center of the test cell flooring to the vertical copper grounding bars. A 12-foot square radiation window through the 3-foot thick south facade of the test cell accesses the four electron-beam transmission tubes of the Aurora Simulator in the cave and machine bay. A 15-foot wide by 12-foot high, 3-foot thick reinforced-concrete door, moved on two 30-ton tandem trolleys on a 26-foot, 6-inch high trolley beam, accesses a nearly 9-foot square radiation test vehicle opening from the staging area at the northwest corner of the test chamber. The radiation door is exterior to the chamber, in the staging area. An additional feature of the test cell is the rectangular grid of 12- to 16-inch width cable trenches, set into the floor slab and connected through the eastern and western earth-filled cells in 8-, 12-, and 16-inch diameter conduits to contractor trailers and the Aurora Simulator data room. Of 16-inch depth, the cable trenches are protected by 2-inch thick steel covers. Two eye-level viewer ports (optical ports), each designed with an incorporated right-angled turn, also connect the test cell and the data room. Ports allow the observation of test objects, 6 feet above the test cell floor, at 4-foot and 30-foot intervals from the machine's point of entry into the cell at the radiation window.

The staging area and mechanical equipment rooms occupy four bays adjacent to the underground test cell at its western corner. Separated from the test chamber by a 10-foot, 8-inch deep test package opening (through one of the earth-filled cells bracketing the test chamber), and sealed from the chamber during testing by a 3-foot thick radiation door, the staging area abuts the data room and its security vault to the southeast and the mechanical equipment rooms to the northwest. The staging area measures 36 feet, 8 inches by 28 feet, 8 inches, with an exterior height of 19 feet from the floor slab to the parapet inclusive of the steel-joist roof structure, metal deck, and built-up sheathing. Interior height is approximately 10 feet, with an acoustical tile ceiling and mechanical duct spacing above. Only the walls facing the test cell and abutting the mechanical equipment rooms and security vault are of reinforced-concrete construction, of 1 feet, 4 inches and 8 feet thickness, respectively. Wood stud-framing sheathed in drywall separates the staging area from the first set-up room in the laboratory and office wing at the southern corner; a 4-foot by 8-foot mechanical generator unit and continued drywall paneling separate the staging area from the data room. A truck dock brackets the staging area to the southwest. Three mechanical bays, one measuring 36 feet, 8 inches by 28 feet and two measuring 36 feet, 8 inches by 18 feet, extend the staging area wing to the northwest and include mechanical and electrical machinery, boiler, and equipment rooms. All exterior walls are of reinforced-concrete construction, varying from 1-foot to 1-foot, 4-inches thick; interior bay and room divisions are of 8-inch reinforced-concrete construction. Roofing system and interior height is continuous from that of the staging area.

The data and control rooms, with attached security vault, are fully internal to the Aurora facility, with no exterior walls. Bracketed by the test cell and cave, a portion of the machine bay, the laboratory and office wing, and the staging area, the data and control room area measures 36 feet, 8 inches by 85 feet, with the control, data, and security rooms being the primary spaces. The data room, of 21-foot by 49-foot dimension and electro-magnetically shielded, is directly connected to the test chamber by seven cable conduits through the bracketing 10-foot, 8-inch earth-filled cell and features two optical ports into the chamber. The control room, abutting the cave and shielded from it by reinforced concrete varying in thickness from 8 to 17 feet, measures 26 feet by 12 feet, 2 inches. The security vault is completely encased in 8-inch reinforced-concrete walls and roof, and is accessed only through the abutting staging area. Of 9-foot interior height, the security vault is completely subsumed within the 19-foot exterior height of the data and control room area; above it are mechanical duct space and steel truss roofing. Smaller rooms in the data and control room area additionally include a crew toilet, a shift room (later, an operations office), a dark room, and a storage room. A 1-foot reinforced-concrete wall separates the crew toilet from the machine bay, but all other walls are of stud-and-drywall construction. Roofing is steel truss with metal decking and exterior height continues that of the staging area and mechanical equipment rooms, with 10-foot interior ceilings in all but the security vault. A 5-foot vestibule separates the data and control room area from the laboratory and office wing to the southwest.

The final component of the Aurora Simulator reinforced-concrete structure is the laboratory and office wing. Measuring 48 feet, 4 inches by 117 feet, 7 inches, the wing features an alignment of three laboratories and two set-up rooms, with library and office space; a central corridor; and an alignment of five single offices, one double office, a conference room, a reception room, and men and women's toilets. Laboratories individually measure 27 feet, 9+ inches by 18 feet and are designated as high-voltage, electronics, and dosimetry labs. As originally designed, a fourth laboratory of slightly lesser width and featuring expanded access to a small office augmented the group; this space was built as a second set-up room (customer/user room), with small technical library adjacent. The original set-up room is accessed from the staging area and, parallel to the added second set-up room, features a separate analysis room/office. With the exception of the exterior 1-foot, 3-inch reinforced-concrete walls enclosing the laboratory and office wing at the northwest and southeast, all walls are of stud-frame and drywall construction. Opposite the 5-foot corridor dividing the laboratories from the remainder of the wing are the offices. Single offices measure 15 feet by 10 feet to 11 feet; reinforced-concrete exterior walls vary from 10 inches to 11 feet in thickness, while most interior walls are of stud-frame and drywall construction. The reception area is also partially bracketed by reinforced-concrete walls. The laboratory and office wing is of uniform height with the data and control room area and the staging and mechanical equipment rooms. Roofing is steel truss with metal decking, a 10-foot interior room height, and accoustical tile ceilings.

Gamma Ray Simulator

The Aurora gamma ray simulator is 161 feet long (inclusive of 135 feet of oil-insulated Marx tank and Blumlein length), 57 feet wide, and 60 feet high, weighing 1,450 tons and capable of being moved on its machine bay tracks a rearwards distance of 70 feet from its operating position for maintenance work. Its Marx generator tank measures 55 feet long, 32 feet wide, and 56 feet high and, when filled with its 1.5 million gallons of insulating oil, adds 5,500 tons further weight. The tank contains four Marx generators, originally comprised of 400 capacitors apiece. Capacitor banks (or columns) were organized in 94 stages, each consisting of four capacitors, and each capacitor rated for charging to 60 kilovolts (60 KV). At each end of the chain of 94 four-capacitor stages was a half stage of two capacitors for an effective total of 95 stages. Capacitor stages were suspended by a system of nylon straps into the Marx generator tank. During tests, after filling the tank with oil, the 1,600 capacitors were charged slowly in parallel and discharged rapidly in series as 10 million-million watts (10 terawatts or 10 trillion watts [10 TW]) of electrical power. With upgrading of the Marx generators during 1989, peak power was re-established at 14 TW. The new Marx features 720 capacitors in its four columns; capacitor columns are organized in 90 stages, each consisting of two capacitors, and each capacitor capable of being charged to 100 KV. In conjunction with the Marx replacement, PSI designed a removable wall that could be inset into the Marx tank to divide the four Marx generator columns into pairs, enabling the production of multiple pulses (Bernstein and Smith 1973, 297; "Aurora Trivia" 1990; Poirier 1995, 1996). The production of multiple pulses at full voltage was not a capability of Aurora's primary competitor, Hermes III (Poirier 1996).

The generated electricity is tailored through oil-filled Blumlein networks to the shape and time-length of pulse desired. (The Blumlein is a triaxial capacitor delivering the pulse to the cathode.) Each of its four Blumlein pulse-forming networks is 62 feet long, with a 23-foot diameter, and consists of three concentric cylinders creating inner and outer transmission lines nested for each network. Blumlein networks and Marx generators are named for Alan Blumlein and Erwin Marx, British scientists of the 1930s. The final voltage pulses are then channeled to four bremsstrahlung tubes (also referenced as diode ducts or beam diodes), moving through these and producing electron field emission between each tube's cathode and tantalum anode. Aurora's typical pulse width, or the time consumed by the electrical burst discharged from the Blumlein networks into the bremsstrahlung transmission tubes, is 180-200 billionths of a second (180-200 ns; originally engineered and operated for Aurora as a pulse width of 150-160 ns, based upon the response time derivative from missile guidance systems in use in ca. 1970 [Fleischmann 1975, 34; Caldwell 1996]). When the accelerated electrons hit the four anodes, bremsstrahlung, or breaking radiation, is created. The bremsstrahlung tubes are simple vacuum chambers with insulating walls containing aluminum grading rings to keep the electric field at the proper orientation with respect to the inclined vacuum surfaces of the lucite (plastic) insulating rings. Tantalum is a dense target for the generated electron beams, thus causing the abrupt stoppage and generating the short-wavelength x-radiation at the gamma end of the spectrum (standard, high-intensity bremsstrahlung).

During the mid-to-late 1980s, Aurora facility managers varied the types of anodes in the simulator, including carbon, tungsten-carbide, and titanium foil targets. Carbon anodes allow the production of less intense bremsstrahlung (moderate bremsstrahlung); tungsten-carbide anodes, in conjunction with a pinched electron beam, allowed production of a very high-intensity bremsstrahlung; and titanium anodes allowed a softened x-ray. Bremsstrahlung closely simulates the gamma radiation of nuclear weapons detonations. Aurora's originally designed maximum radiation dosage is produced as a convergence of the radiation emitted from the four bremsstrahlung tubes, creating a spherical hot spot of 45,000 rads (45 kRad [Si]) a foot in diameter and 70 inches above the test cell floor. (Nuclear radiation is measured relative to the silicon in electronic components.) With upgrading throughout the 1980s, DNA modified Aurora to produce extremely intense radiation over small objects (300 kRad [Si] over the size of a baseball), with irradiation of much larger areas, such as full satellites and tanks, achieved at lesser exposures further back in the test cell from the radiation window (.675 kRad [Si]). Aurora physicists produced a record dose of 560 kRad (Si) over the volume of a golf ball in 1983 using the pinched electron beam ("Aurora Enjoys a Banner Year" 1983). The total electrical on-time of the Aurora Simulator, that is the combined time of the electrical bursts required to generate the test radiation (1972-1995), was approximately 1.5 thousandths of a second (1.5 millisecond [1.5 ms]) and was representative of 9,100+ test shots.

Major Modifications to Infrastructure and Machinery

The Aurora Simulator has undergone relatively few major modifications during its 24 years of activity. These alterations to the infrastructure, to the gamma ray effects simulator itself, and to the laboratory equipment, however, are significant as evocations of changing strategic and tactical military Cold War policies.

Major infrastructural, simulator, and laboratory modifications at Aurora generally complemented the new maximum radiation doses, peak power, and voltages, and accommodated test vehicle sizes possible at Hermes. Although Aurora did add a capability to shorten its typically used pulse width from 180/190 ns to 120/135 ns, the Adelphi laboratory never, as standard test practice, approached the much shorter pulse widths of 21-28 ns achieved by Hermes III. Of more significant note are the respective typical rise times at Aurora and Hermes III: 65 ns for Aurora and 11 ns for Hermes III. Rise times, the duration of time needed to come to full output voltage, require much greater cleverness and are much harder to achieve. Hermes III, built for the DOE Sandia Laboratories in Albuquerque, New Mexico, and operational in 1988, is today the only gamma ray simulator operational, of very large type, in the United States.

Infrastructure

The primary change to the Aurora Simulator infrastructure was the addition of a second access door to the test cell. The original access door accommodated test packages no larger than the nuclear weapons components seated atop a missile, reflective of the strategic interpretation that the Army's role in Europe would not be prominent following the outbreak of a nuclear war. By the middle 1970s, the strategic, and by the middle 1980s, the tactical, interpretations had changed. The Army's role was seen as significant, with a pronounced need for hardened weaponry (such as tanks). With the advent of the Reagan era and SDI (Star Wars), large tactical systems, such as the Milstar satellite, were also subject to the requirements of nuclear tests. The second access door, nearly doubled in both height and width from the parameters of the original door (left in place), acknowledges the important shift in testing needs. Door construction began in late 1984.

Gamma Ray Simulator

Aurora managers made several important changes to the Aurora Simulator during the late 1980s. The first change evolved during the middle and late 1980s. Through the modification of the front end of the simulator, specifically through the use of several different materials as anodes; through the pinching of the electron beam in the test cell; through the confinement of the beam by a magnetic field coil; and through the use of a paraffin scatterer, the original Aurora radiation environment was expanded from solely high-intensity bremsstrahlung to moderate bremsstrahlung (carbon anodes); very high-intensity bremsstrahlung (very intense radiation) for maximum doses over small test objects (tantalum or tungsten-carbide anodes with pinched beams); direct irradiation by electron beam (magnetic field coil); and soft x-ray environments (titanium anodes with paraffin scatterer).

The second major change in the simulator was the replacement of the original Marx generators in 1989. As designed and built, the four Marx generators of 1970, with 1,600 capacitors, required very heavy maintenance, particularly due to carbon buildup. The 1989 generators, with only 720 capacitors, in addition to improving maintenance efficiency, also increased peak voltage to 12-15 MV (12-15 megavolts [12-15 MV]), allowing the generators to charge much faster. The 1989 Marx, designed by PI like the 1970 machine, had better spark gaps and its capacitors held substantially more energy; with only 45 percent of the original number of capacitors housed in the same tank space, the Marx ran far better than it had during its first 20 years. The added removable wall, halving the Marx columns into two sets of two, further made it possible to fire two of the Marx generators at one voltage and to follow the first firing with a second at a dosage and time lapse experimentally variable. This particular feature, completely unique to Aurora, was only a weapons testing need for about 24 months, allowing the double irradiation of objects in the test cell, and was neither an original feature or modification undertaken for Hermes III (DNA ca. 1990; Poirier 1996). Following the replacement of the Marx generators, Aurora's pulse width and rise time could be varied between 30 ns and 150 ns, and between 18 ns and 80 ns. In 1990, Aurora personnel painted the Marx generator tank a deep federal blue trimmed in periwinkle, visually reflective of the new state-of-the-art generators housed in the tank. (The tank had originally been painted a Defense Department light green.)

Laboratory Equipment

In conjunction with the modification of the front end of the simulator and the replacement of the Marx generators, DNA also upgraded the laboratory instrumentation to accommodate taking more test measurements simultaneously. The original oscilloscopes had the ability to record up to 36 measurements during one test; the late 1980s transient waveform digitizers nearly doubled these parameters, accommodating up to 60 measurements per test. The packages tested in Aurora's first years did not require such complex equipment in the laboratory. During the last years, however, testing of the MX subsystems, in particular, necessitated the enhanced capabilities. At such times as the full 60 digitizers were not needed, two to three customers could use the test cell together. During multiple concurrent testing on differing packages, placement in the test cell, front-to-back, created a useful range of radiation dosages over varied-size objects, while also making Aurora more cost-efficient.

Citations of Peak Electrical Parameters

In conclusion, it should be noted that published peak electrical parameters for the Aurora Simulator vary and in all cases represent some form of simplification. Historically, Aurora is referenced as a 10 MV machine. Actually, the standard high value for voltage is more reasonably agreed upon by the physicist community as 8 MV, inclusive of the middle 1980s improvements to the Marx generators. References to 12 MV and 15 MV represent an ideal peak, to which the simulator was not actually pushed, and 10 MV would have required routine costly maintenance work. Peak published wattage varies in a parallel manner, with 8 TW closer to the real standard high value, and figures from 10 TW to 18 TW found in print. Marketing and strategic needs further influenced cited performances (Huttlin 1996).

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Reel 1: Preparation of an outermost Blumlein cylinder and interior placement. Close-up of the capacitors of a Marx generator column. Undated.

Reel 2: Insertion of an inner Blumlein cylinder. Preparation of second outermost and inner Blumlein cylinders. Interior placement and insertion. Overall scan of the exterior of the Aurora infrastructure, entrance facade. Vertical scan of the exterior of the Marx tank. Undated.

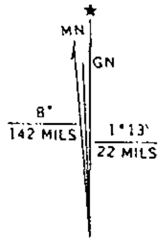
Reel 3: General interior scans. Close-up of several men, including Alexander Stewart. Multiple views of Blumlein cylinders, before final placement and following permanent configuration of the four Blumlein concentric cylinder sets. Undated.

Reel 4: General interior scans. Multiple views of Blumlein cylinders, including views from front end and from above. Welding details, with men inside Blumlein cylinders. Close-up of small white and brown dog. Undated.

Reel 5: First views of test cell. Excellent footage of hoisting and stacking of aluminum grading rings for the bremsstrahlung tubes. July 9-10, 1971.

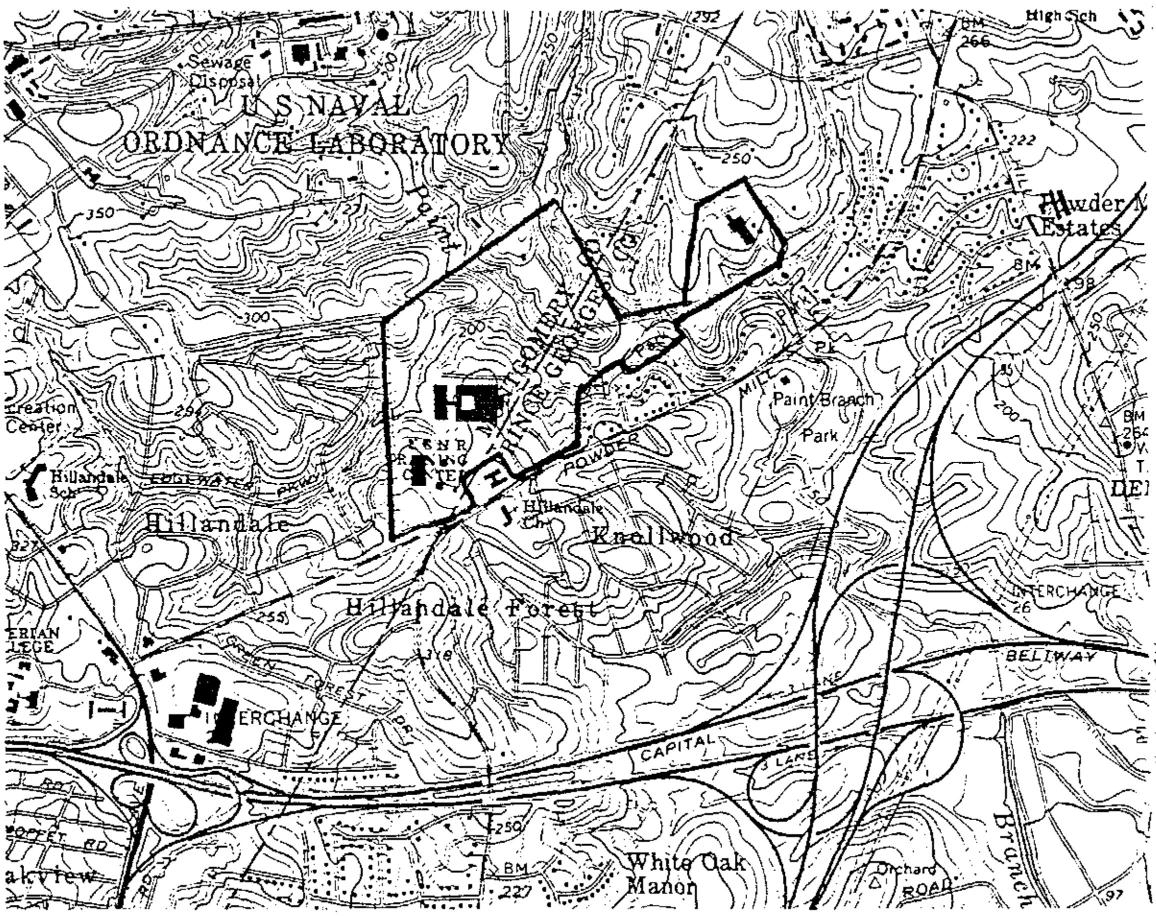
Reel 6: Continued footage of hoisting and stacking aluminum grading rings. Completion of bremsstrahlung tubes. Unusual footage of a man jumping, and then dancing, atop completed (but not yet placed) tube. Footage of military officers arriving at Aurora, with Aurora personnel. Mating of Blumleins and bremsstrahlung tubes. Outstanding reel. July 10, 13, 16, and 30, 1971.

Reel 7: Scans of finished Marx tank and test cell. Close-up of the radiation window to the test cell. June 4, 1972.



UTM GRID AND 1979 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

BELTSVILLE QUADRANGLE
MARYLAND
7.5 MINUTE SERIES (TOPOGRAPHIC)
SW/4 LAUREL 15' QUADRANGLE



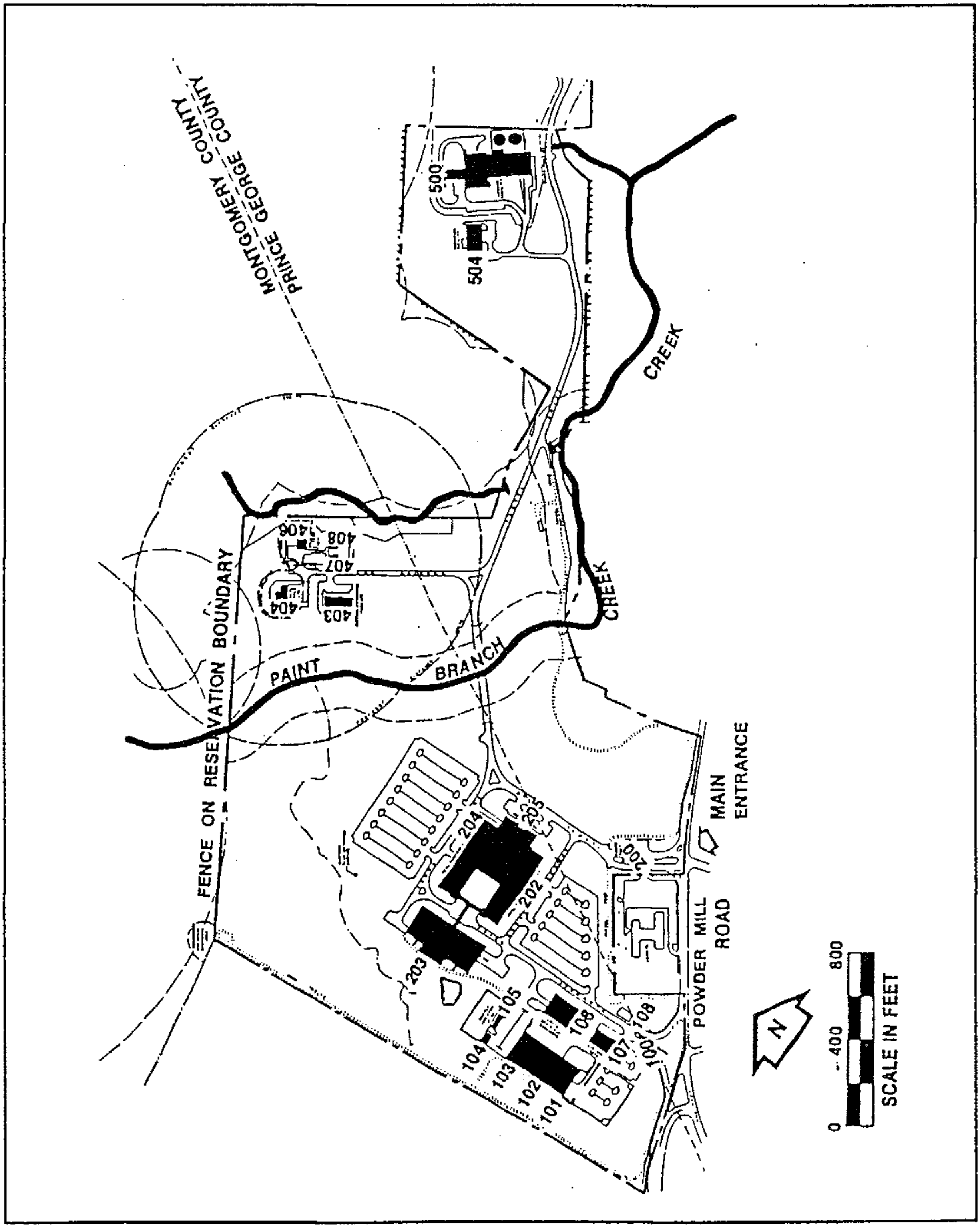
SCALE 1:24 000

1 ½ 0 1 MILE

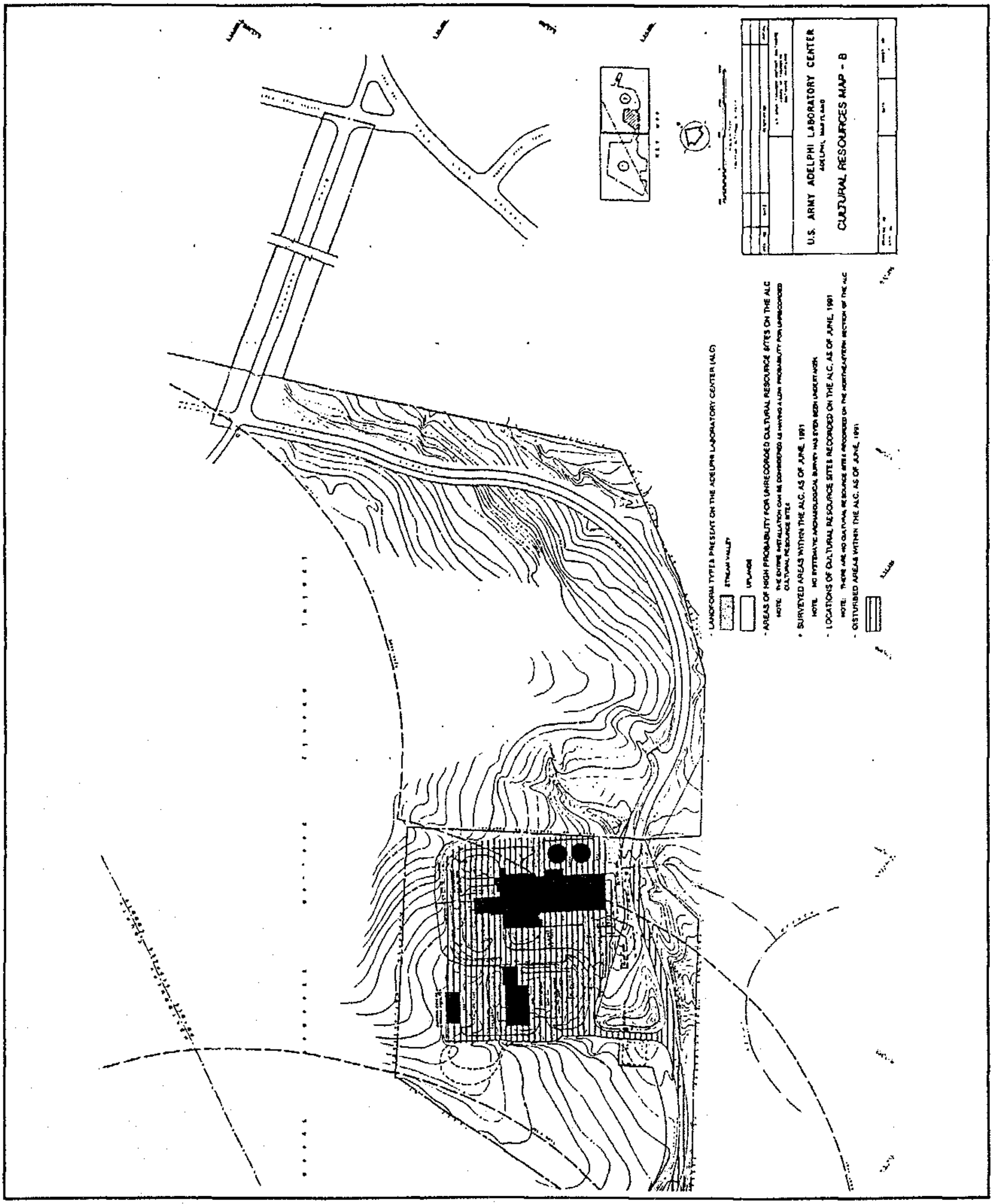
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

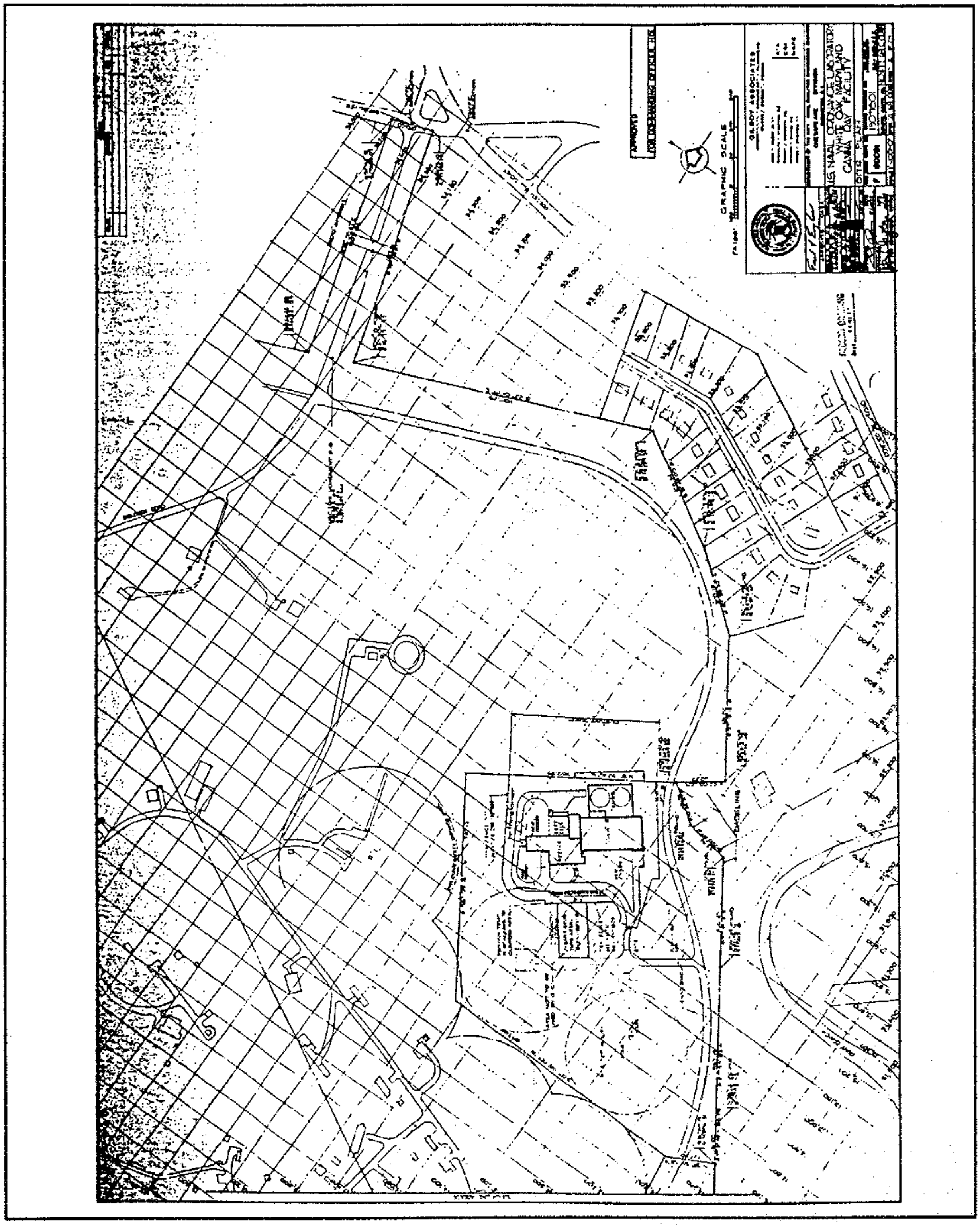
1 .5 0 1 KILOMETER

CONTOUR INTERVAL 10 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

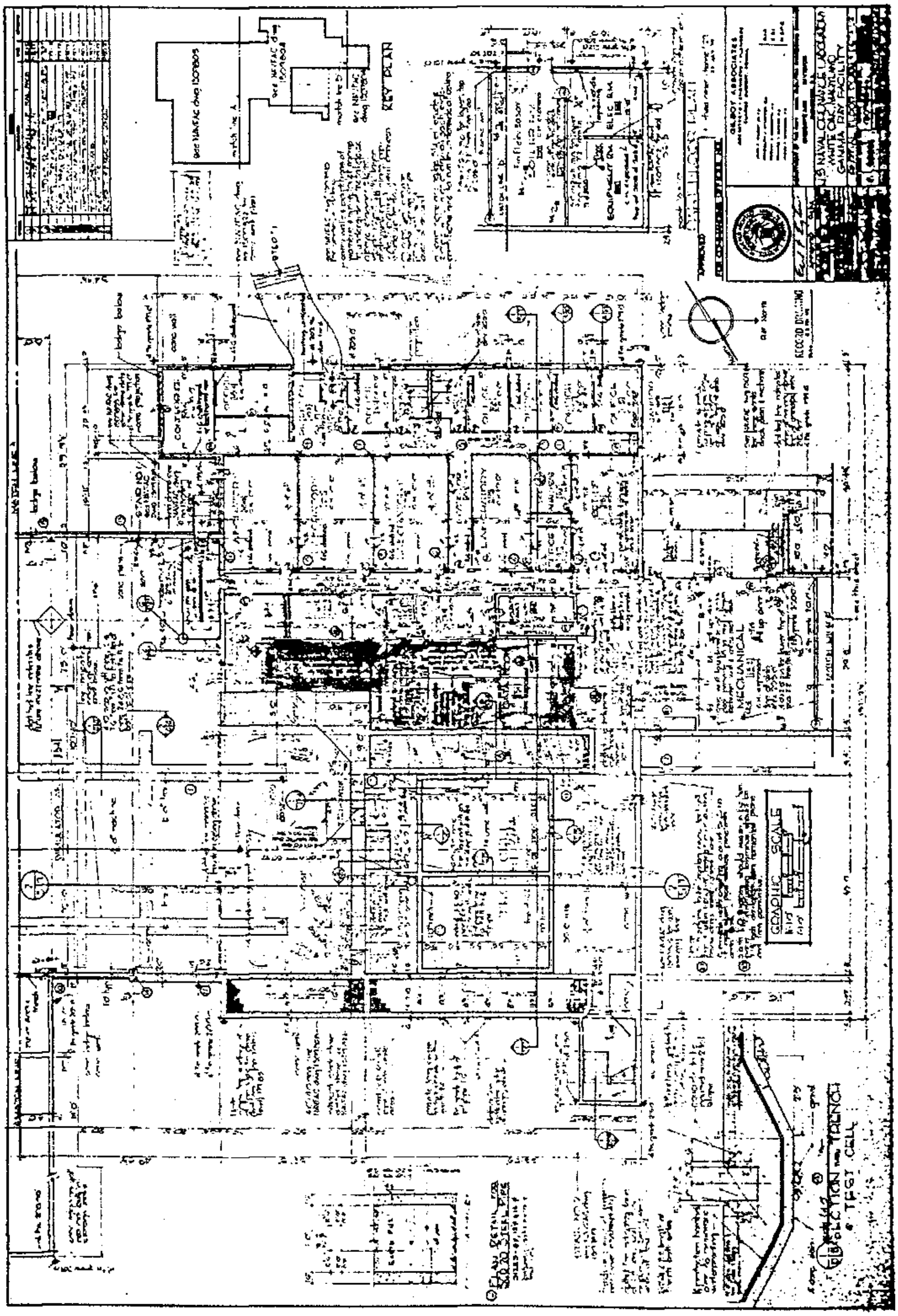


Location of Building 500, the Aurora Pulsed Radiation Simulator, within the United States Army Research Laboratory, Adelphi Maryland.

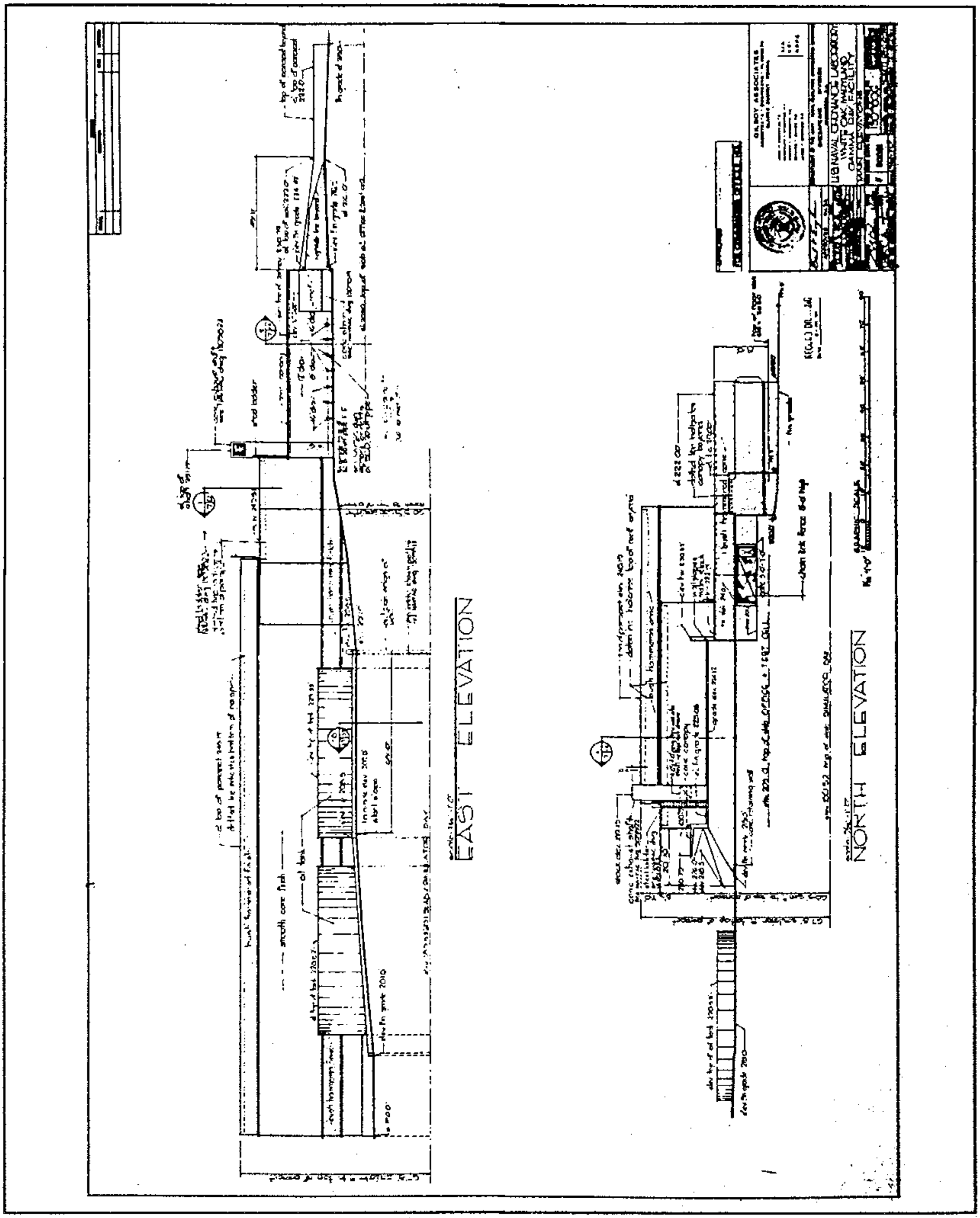

U.S. ARMY ADELPHI LABORATORY CENTER
CULTURAL RESOURCES MAP - B
LANDFORM TYPES PRESENT ON THE ADELPHI LABORATORY CENTER (ALC)
STREAM VALLEY
UPLANDS
AREAS OF HIGH PROBABILITY FOR UNRECORDED CULTURAL RESOURCE SITES ON THE ALC
SURVEYED AREAS WITHIN THE ALC AS OF JUNE, 1991
LOCATIONS OF CULTURAL RESOURCE SITES RECORDED ON THE ALC AS OF JUNE, 1991
DISTURBED AREAS WITHIN THE ALC AS OF JUNE, 1991



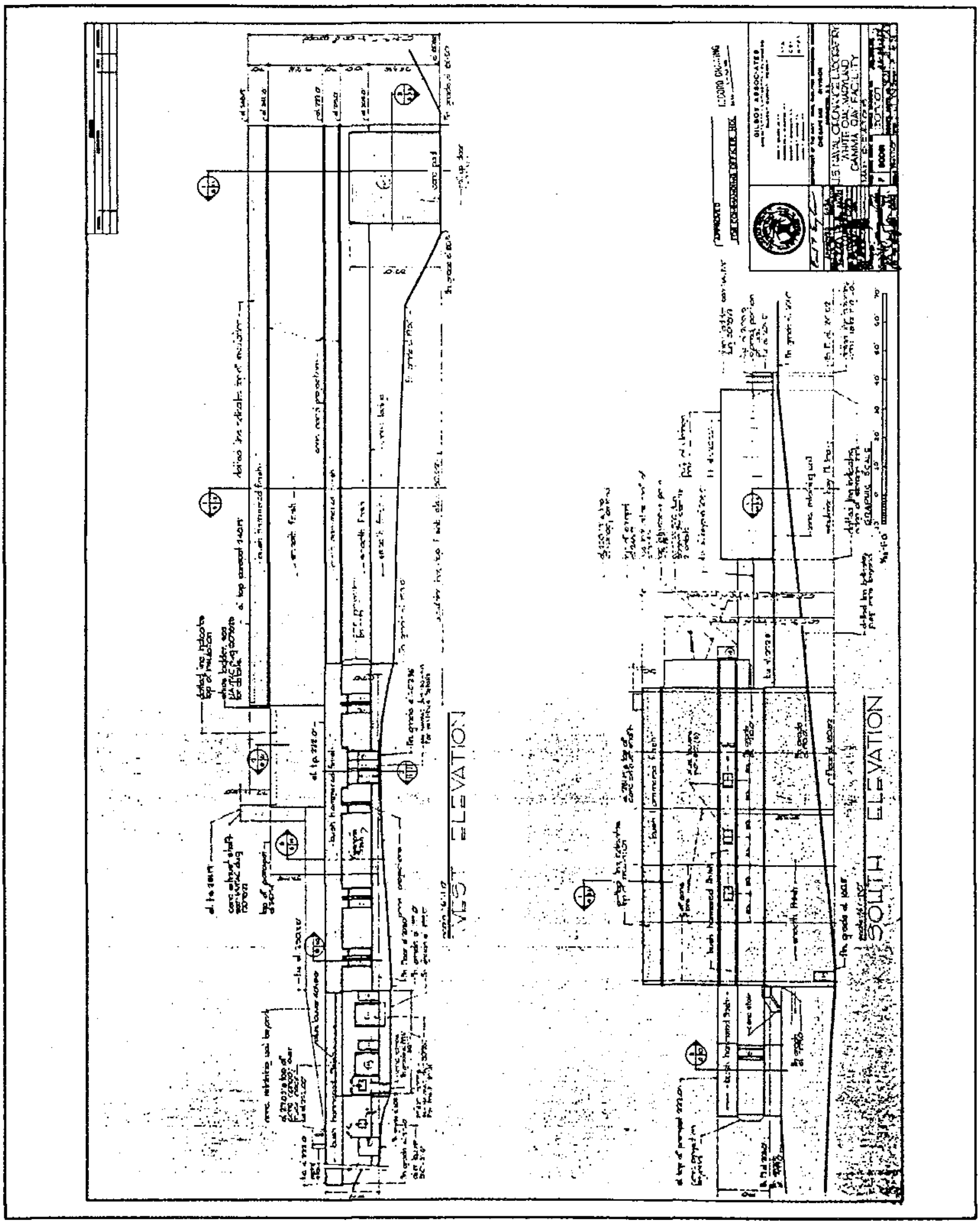
Drawing No. 1309801, U.S. Naval Ordnance Laboratory, White Oak, Maryland, Gamma Ray Facility, site plan, 1969.



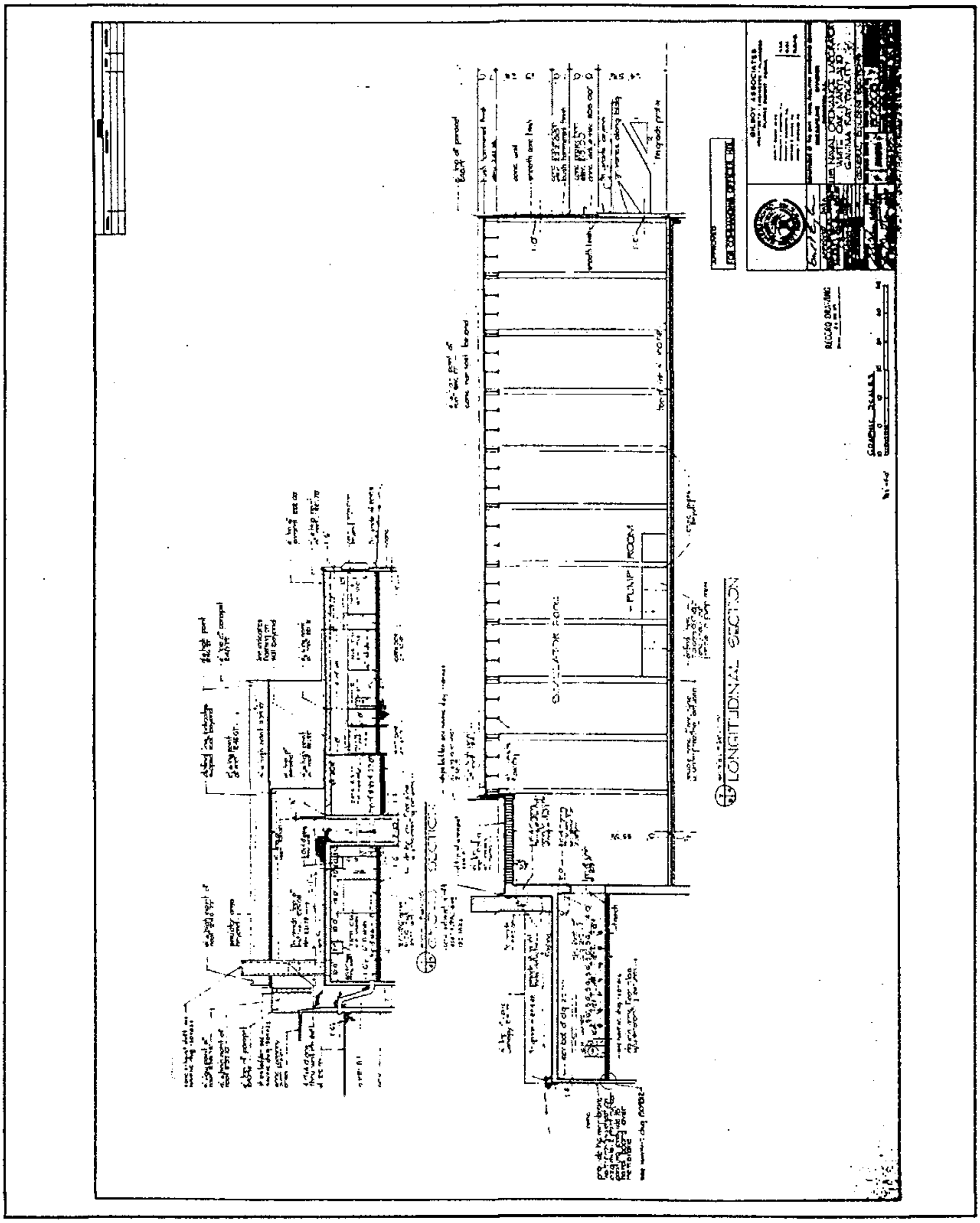
Drawing No. 1309804, U.S. Naval Ordnance Laboratory, White Oak, Maryland, Gamma Ray Facility, partial floor plan and details, 1969.



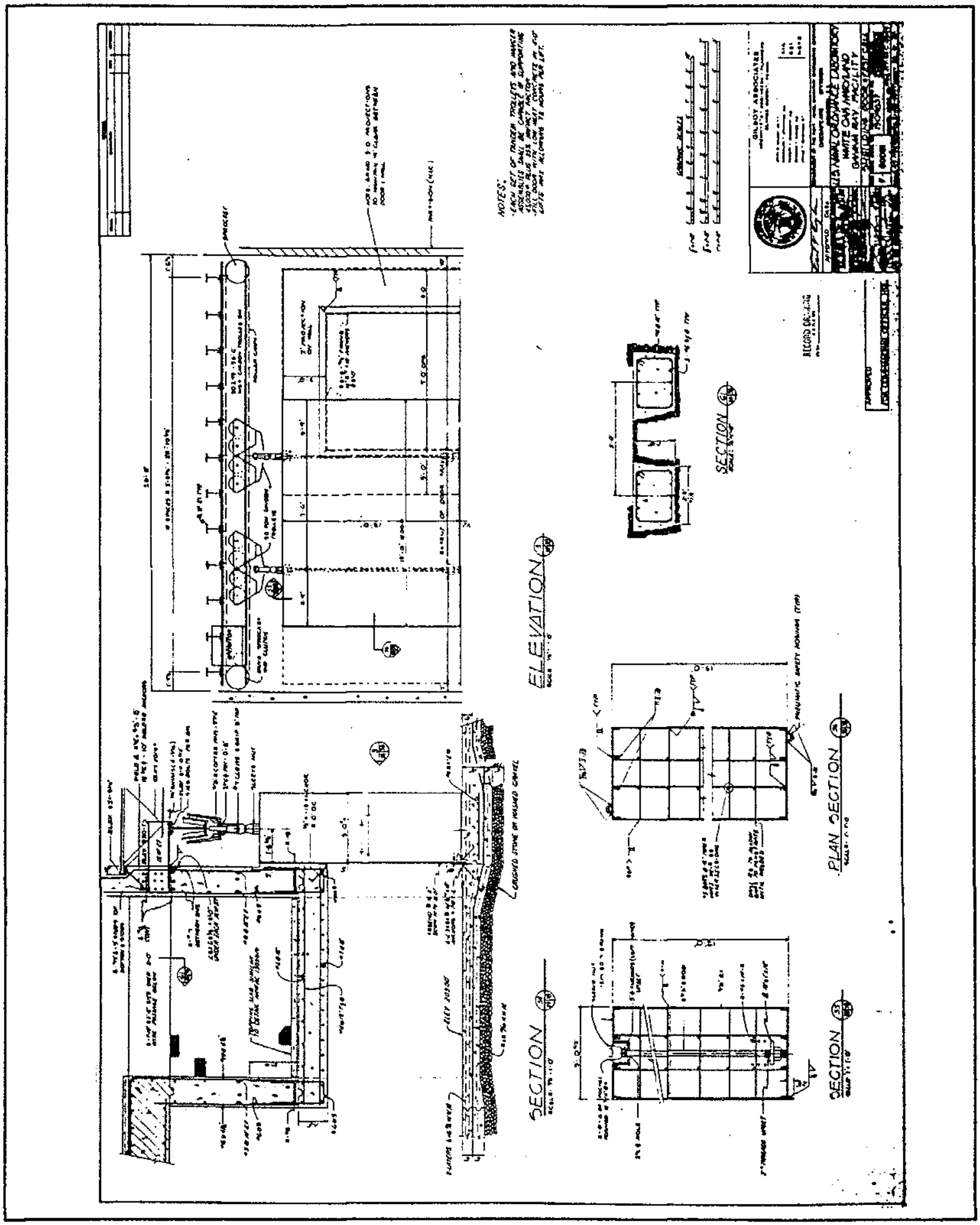
Drawing No. 1309806, U.S. Naval Ordnance Laboratory, White Oak, Maryland, Gamma Ray Facility, main elevations, 1969.



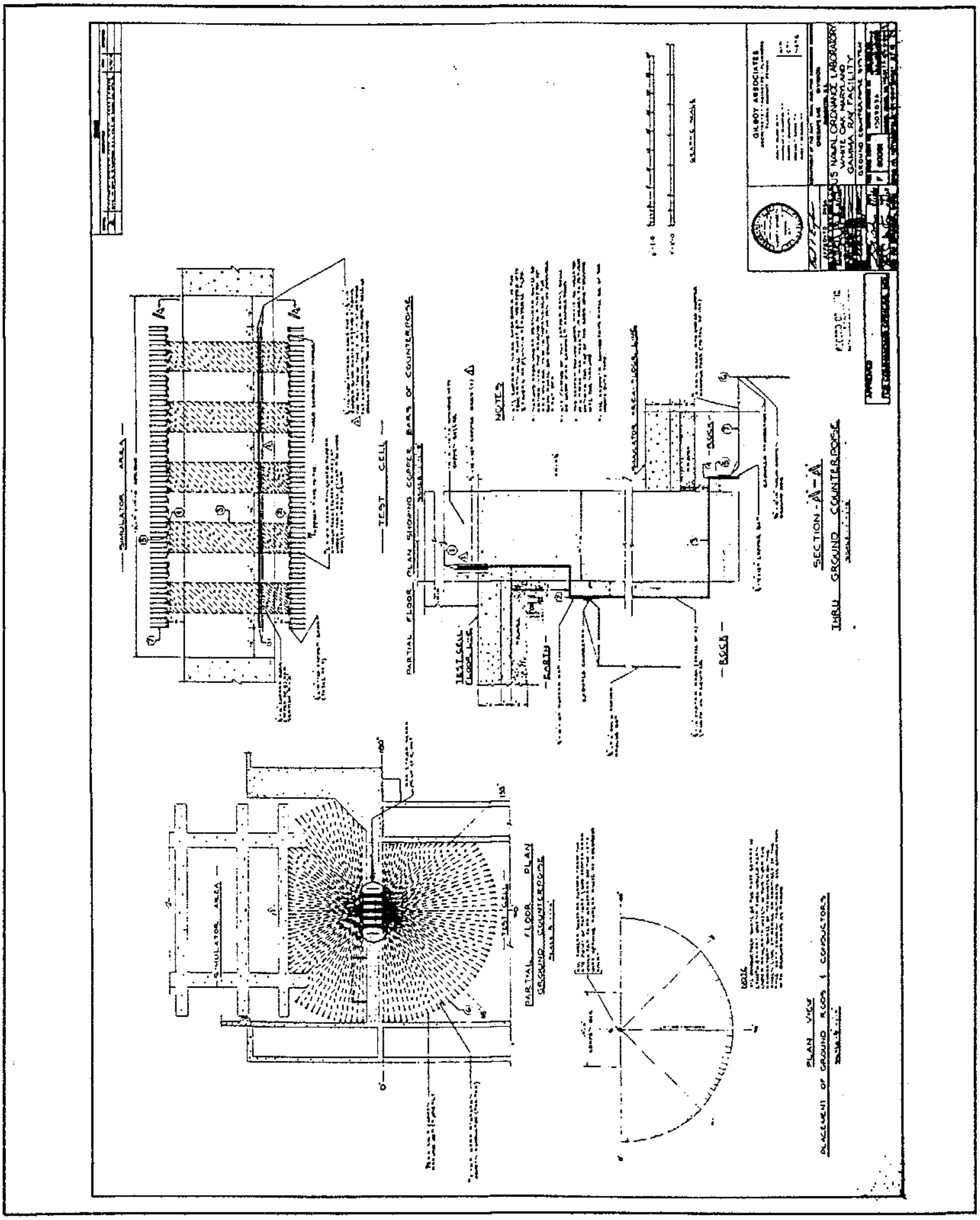
Drawing No. 1309807, U.S. Naval Ordnance Laboratory, White Oak, Maryland, Gamma Ray Facility, main elevations, 1969.



Drawing No. 1309808, U.S. Naval Ordnance Laboratory, White Oak, Maryland, Gamma Ray Facility, general building sections, 1969.



Drawing No. 1309837, U.S. Naval Ordnance Laboratory, White Oak, Maryland, Gamma Ray Facility, shielding door and test cell, 1969.



Drawing No. 1309856, U.S. Naval Ordnance Laboratory, White Oak, Maryland, Gamma Ray Facility, ground counterpoise system, 1969.